Appendix B

Technical Memoranda and Reports

Disclaimer:

Technical memoranda and reports were prepared as independent documents to support the preparation of the Supplemental Draft Environmental Impact Statement (SDEIS) for the Dallas CBD Second Light Rail Alignment (D2 Subway). Information from these documents was incorporated into the SDEIS to provide information on existing conditions, and in some cases, assess potential impacts to the resources. Information contained in the SDEIS is the most current and supersedes information in the technical memoranda and reports.

B-10

Noise and Vibration Technical Report (January 2019) and East End Addendum Technical Memorandum (February 2020)

Noise and Vibration Technical Report

DART Dallas CBD Second Light Rail Alignment (D2 Subway)

Final

Dallas, TX
January 22, 2019

This Report was Prepared for DART
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1 Introduction and Summary

Cross-Spectrum Acoustics Inc. (CSA) has conducted a noise and vibration impact assessment for the Dallas Area Rapid Transit (DART) Dallas CBD Second Light Rail Alignment, commonly referred to as D2 Subway.

A noise and vibration impact assessment and mitigation development have been carried out in accordance with the guidelines specified in the U.S. Federal Transit Administration (FTA) *Transit Noise and Vibration Impact Assessment Manual* (FTA, 2018) and in the DART policy document *Environmental Impact Assessment & Mitigation Guidelines for Transit Projects* (August 2017). The assessment was carried out in support of the Environmental Impact Statement (EIS) for the D2 Subway. The objective of the assessment was to document the potential noise and vibration impacts at sensitive locations and identify appropriate mitigation measures as a part of the project.

Based on the screening distances provided in Section 4.3 of the FTA manual, the noise study area for the project was typically within 350 feet of the alignment. Based on the screening distances provided in Section 6.3 of the FTA manual, the vibration study area for the project was typically limited to within 150 feet of the alignment, except for highly vibration-sensitive land uses where facilities within about 450 feet of the alignment were considered.

Following a summary of the assessment results in the subsections below, Section 2 provides a discussion of noise and vibration basics and Section 3 describes the impact criteria. Section 4 discusses the affected environment, including a description of noise and vibration sensitive land uses and the measurements conducted to determine the existing noise and vibration conditions. Section 5 describes the methodology used for noise and vibration prediction, Section 6 includes the results of the noise and vibration impact assessment, and potential mitigation measures are described in Section 7. Finally, Appendix A includes photographs of the noise and vibration measurement sites, and noise and vibration data are provided in Appendix B and Appendix C, respectively.

1.1 Noise Impact Assessment

The results of the noise impact assessment identified a total of 230 moderate noise impacts from light rail operation, including residential units at the W Dallas Residences, the Vista Apartments, the Northend Apartments and the Live Oak Lofts. Because the noise increases are projected to be less than 3 dB at all of these locations, noise mitigation is not required based on DART policy. However, there is the potential for additional noise impact from wheel squeal at sensitive receptors near curves in the D2 alignment and therefore wheel/rail lubrication measures should be considered at such locations. There is also the potential for additional noise impact at locations above the subway portions of the alignment due to fan noise and train noise transmitted to the surface through ventilation shafts and gratings. Noise from these sources will be evaluated during project design when detailed information becomes available, and mitigation measures will then be developed as appropriate.

1.2 Vibration Impact Assessment

Vibration from light rail operations is of particular concern to stakeholders along the D2 project alignment. The results of the vibration impact assessment identified the potential for ground-borne vibration impact at 36 residences and for ground-borne noise impact at 54 residences, all at the Live Oak Lofts. All these impacts are related to annoyance rather than damage effects. Because the nearby crossover is expected to be a major source of vibration, it is recommended that special frogs be considered for this crossover. Given that the track is embedded at this location, flange-bearing frogs may be the most practical measure.

Although the use of special frogs could eliminate the vibration impact at the Live Oak Lofts, this measure would not be sufficient to eliminate the ground-borne noise impact. Therefore, some type of resilient track support should also be considered at this location. However, it is recommended that a more detailed vibration analysis, including ground-to-building vibration propagation testing, be conducted at this and other buildings of concern during project design to make a final determination regarding impact and any required mitigation.

1.3 Construction Noise and Vibration

Vibration during construction of the D2 Project is a concern of the Texas Historical Commission/State Historic Preservation Office (THC/SHPO), particularly with regard to potential damage to historic buildings along Commerce Street. Therefore, it is recommended that blasting be avoided during project construction, if at all possible.

Other than blasting, tunnel boring machine (TBM) operations and the potential use of muck trains for spoils removal would be expected to generate the highest vibration levels. An assessment of tunneling vibration indicated that there is the potential for ground-borne vibration impact at the KDFW FOX4 TV Studio from both TBM and muck train operations. In addition, 173 ground-borne noise impacts are anticipated due to muck train operations, including spaces in nearly all of the sensitive buildings adjacent to the proposed tunnel. However, the projected vibration levels from TBM and muck train operations are all well below the most stringent FTA damage criteria for buildings that are extremely susceptible to vibration damage.

A quantitative assessment of construction noise and vibration impacts from tunneling and other activities will be conducted during the design phase of the Project when detailed construction scenarios are available. In particular, potential construction-related impacts to historic/special structures will be considered. Specific construction noise and vibration mitigation measures will then be developed as appropriate, and requirements for noise and vibration monitoring will be evaluated.

2 Noise and Vibration Concepts

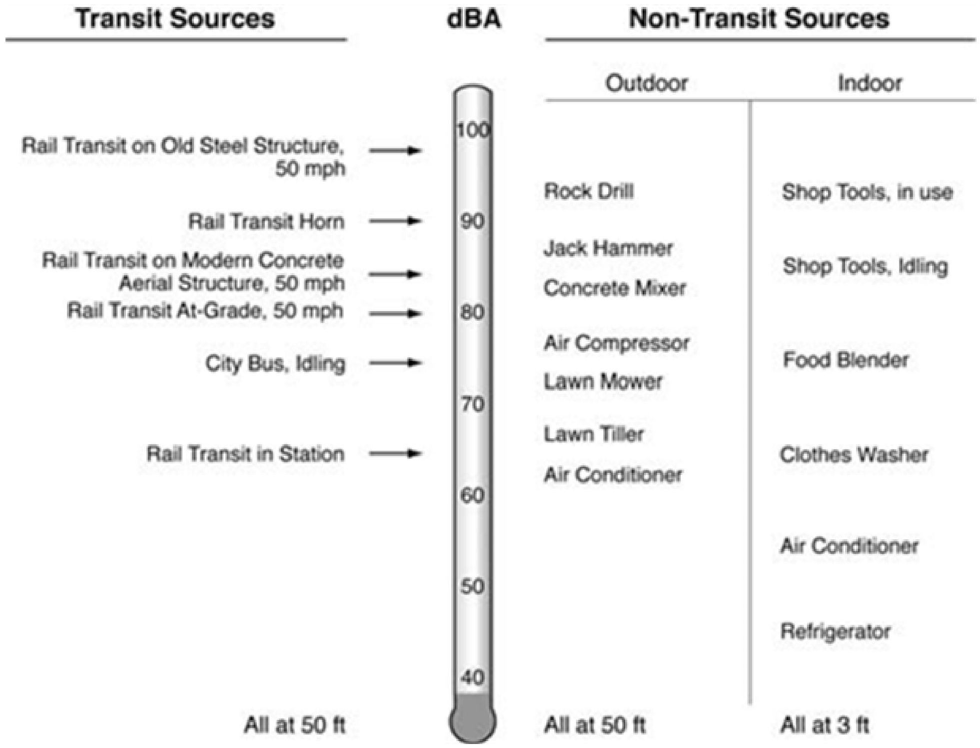
2.1 Noise Fundamentals and Descriptors

Sound is defined as small changes in air pressure above and below the standard atmospheric pressure and noise is usually considered to be unwanted sound. The three parameters that define noise include:

- Level: The level of sound is the magnitude of air pressure change above and below atmospheric pressure, and is expressed in decibels (dB). Typical sounds fall within a range between 0 dB (the approximate lower limit of human hearing) and 120 dB (the highest sound level generally experienced in the environment). A 3 dB change in sound level is perceived as a barely noticeable change outdoors and a 10 dB change in sound level is perceived as a doubling (or halving) of loudness.
- Frequency: The frequency (pitch or tone) of sound is the rate of air pressure change and is expressed in cycles per second, or Hertz (Hz). Human ears can detect a wide range of frequencies from around 20 Hz to 20,000 Hz; however, human hearing is not as sensitive at high and low frequencies, and the A weighting system, which measures what humans hear in a more meaningful way by reducing the sound levels of higher and lower frequency sounds, is used to provide a measure (dBA) that correlates with human response to noise. **Figure 2-1** shows typical maximum A-weighted sound levels for transit and non-transit sources. The A-weighted sound level has been widely adopted by acousticians as the most appropriate descriptor for environmental noise.
- Time Pattern: Because environmental noise is constantly changing, it is common to condense all of this information into a single number, called the "equivalent" sound level (Leq). The Leq represents the changing sound level over a period of time, typically 1 hour or 24-hours in transit noise assessments. For assessing the noise impact of rail projects at residential land use, the Day-Night Sound Level (Ldn) is the noise descriptor commonly used, and it has been adopted by many agencies as the best way to describe how people respond to noise in their environment. Ldn is a 24-hour cumulative A-weighted noise level that includes all noises that occur during a day, with a 10-dB penalty for nighttime noise (10 pm to 7 am). This nighttime penalty means that any noise events at night are equivalent to ten similar events during the day. Typical Ldn values for various transit operations and environments are shown on **Figure 2-2**.

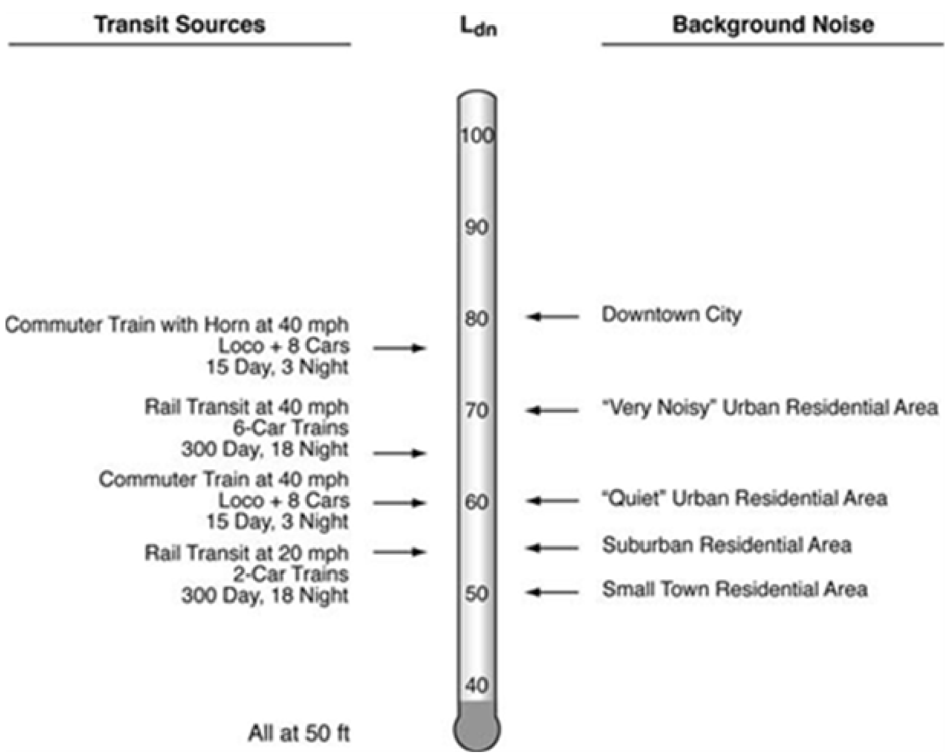
In addition to the Leq and Ldn, there is another descriptor used to describe noise. The loudest 1 second of noise over a measurement period, or maximum A-weighted sound pressure level (Lmax), is used in many local and state ordinances for noise emitted from private land uses and for construction noise impact evaluations.

FIGURE 2-1. TYPICAL A-WEIGHTED SOUND LEVELS



Source: FTA, 2018

FIGURE 2-2. TYPICAL Ldn NOISE EXPOSURE LEVELS



Source: FTA, 2018

2.2 Vibration Fundamentals and Descriptors

Ground-borne vibration from trains refers to the fluctuating or oscillatory motion experienced by persons on the ground and in buildings near railroad tracks. Vibration can be described in terms of displacement, velocity, or acceleration. Displacement is the easiest descriptor to understand. For a vibrating floor, the displacement is simply the distance that a point on the floor moves away from its static position. Velocity represents the instantaneous speed of the floor movement, and acceleration is the rate of change of the speed. Although displacement is easier to understand, the response of humans, buildings, and equipment to vibration is more accurately described using velocity or acceleration.

Two methods are used for quantifying vibration. The peak particle velocity (PPV) is defined as the maximum instantaneous positive or negative peak of the vibration signal. PPV often is used in monitoring of blasting vibration, since it is related to the stresses experienced by buildings.

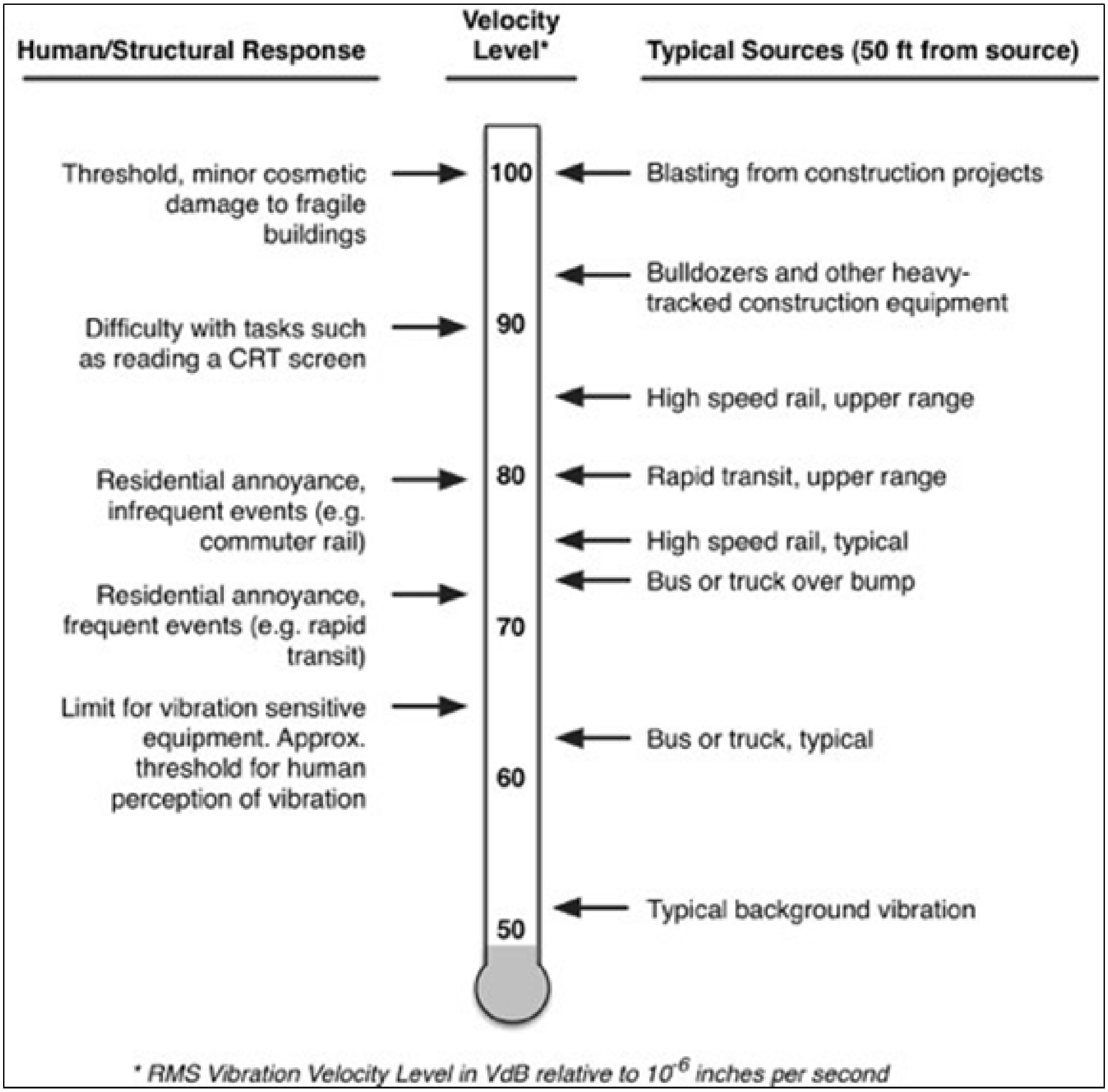
Although PPV is appropriate for evaluating the potential of building damage, it is not suitable for evaluating human response. It takes some time for the human body to respond to vibration impulses. In a sense, the human body responds to an average of the vibration amplitude. Because the net average of a vibration signal is zero, the root mean square (RMS) amplitude is used to describe the "smoothed" vibration amplitude.

PPV and RMS velocities are normally described in inches per second in the U.S. and in meters per second in the rest of the world. Although it is not universally accepted, decibel notation is in common use for vibration. Decibel notation compresses the range of numbers required to describe vibration. Vibration levels in this report are referenced to 1×10^{-6} inches per second (in/sec). Although not a universally accepted notation, the abbreviation "VdB" is used in this document for vibration decibels to reduce the potential for confusion with sound decibels.

Common vibration sources and human and structural responses to ground-borne vibration are illustrated in **Figure 2-3**. Typical vibration levels can range from below 50 VdB to 100 VdB (0.000316 in/sec to 0.1 in/sec). The human threshold of perception is approximately 65 VdB.

Ground-borne noise is a low-volume, low-frequency rumble inside buildings, resulting when ground vibration causes the flexible walls of the building to resonate and generate noise. Ground-borne noise is normally not a consideration when trains are elevated or at grade. In these situations, the airborne noise usually overwhelms ground-borne noise, so the airborne noise level is the major consideration. However, ground-borne noise becomes an important consideration where there are sections of the corridor that are in a tunnel or where sensitive interior spaces are well-isolated from the airborne noise. In these situations, airborne noise is not a major path and ground-borne noise becomes the most important path into the building. Ground-borne noise may also need to be considered in cases where the airborne noise from a project is mitigated by a sound wall.

FIGURE 2-3. TYPICAL LEVELS OF GROUND-BORNE VIBRATION



Source: FTA, 2018

3 Noise and Vibration Criteria

The noise and vibration impact criteria used for the Project are based on information contained in the FTA noise and vibration guidance manual. The criteria used to assess noise and vibration impacts from train operations and construction activities are described below.

3.1 Operational Noise Impact Criteria

The FTA operational noise impact criteria are based on well-documented research on community response to noise and are based on both the existing level of noise and the change in noise exposure due to a project. The FTA noise criteria compares the Project noise with the existing noise (not the no-build noise). This is because comparison of a noise projection with an existing noise condition is more accurate than comparison of a projection with another noise projection. Because background noise may increase by the time the project is operational, this approach of using existing noise conditions is conservative.

The FTA noise criteria are based on the land use category of the sensitive receptor. The descriptors and criteria for assessing noise impacts vary according to land use categories adjacent to the track. For Category 2 land uses where people live and sleep (e.g., residential neighborhoods, hospitals, and hotels), the Ldn is the assessment parameter. For other land use types (Category 1 or 3) where there are noise-sensitive uses (e.g., outdoor concert areas, schools, and libraries), the Leq for an hour of noise sensitivity that coincides with train activity is the assessment parameter. **Table 3-1** summarizes the three land use categories.

TABLE 3-1. LAND USE CATEGORIES AND METRICS FOR TRANSIT NOISE IMPACT CRITERIA

Land Use Category	Land Use Type	Noise Metric (dBA)	Description of Land Use Category
1	High Sensitivity	Outdoor Leq(1h) *	Land where quiet is an essential element of its intended purpose. Example land uses include preserved land for serenity and quiet, outdoor amphitheaters and concert pavilions, and national historic landmarks with considerable outdoor use. Recording studios and concert halls are also included in this category.
2	Residential	Outdoor Ldn	This category is applicable to all residential land use and buildings where people normally sleep, such as hotels and hospitals.
3	Institutional	Outdoor Leq(1h)*	This category is applicable to institutional land uses with primarily daytime and evening use. Example land uses include schools, libraries, theaters, and churches where it is important to avoid interference with such activities as speech, meditation and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds and recreational facilities are also included in this category.

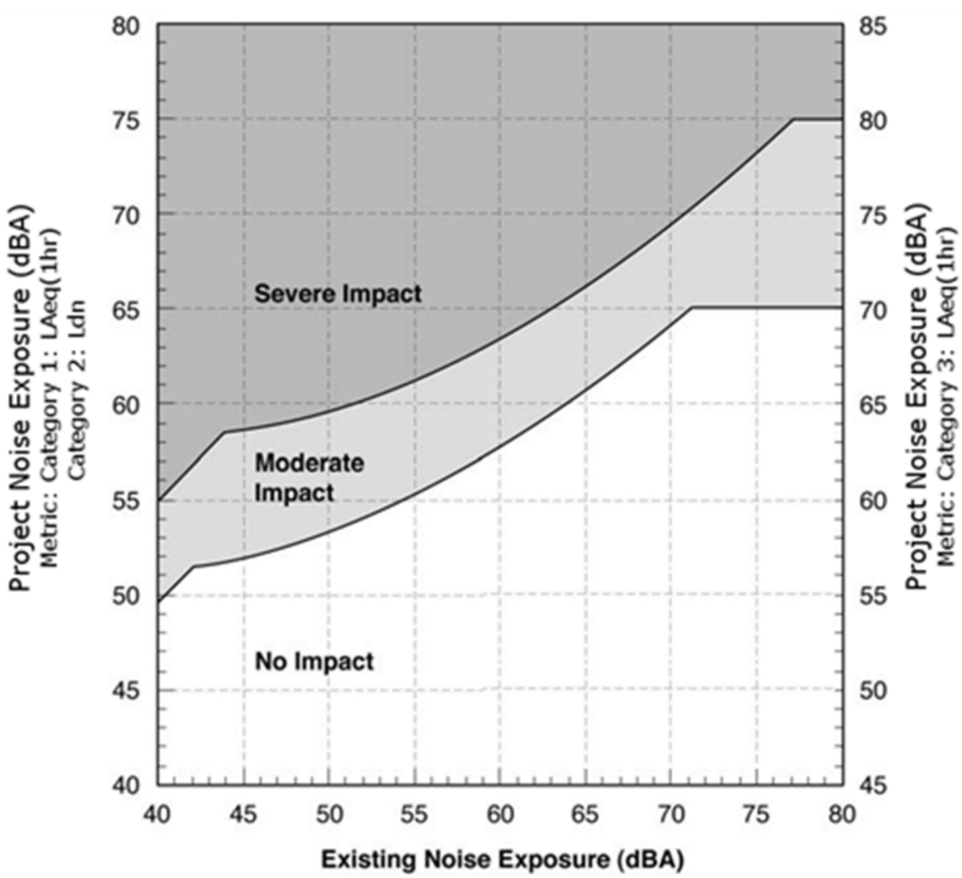
* Leq(1hr) for the loudest hour of project-related activity during hours of noise sensitivity.

Source: FTA, 2018

The noise impact criteria are defined by the two curves shown in **Figure 3-1**, which allow increasing project noise as existing noise levels increase, up to a point at which impact is determined based on project noise alone. The FTA noise impact criteria includes three levels of impact, as shown on **Figure 3-1**. The three levels of impact include:

- **No Impact:** Project-generated noise is not likely to cause community annoyance. Noise projections in this range are considered acceptable by FTA and mitigation is not required.
- **Moderate Impact:** Project-generated noise in this range is considered to cause impact at the threshold of measurable annoyance. Moderate impacts serve as an alert to project planners for potential adverse impacts and complaints from the community. Mitigation should be considered at this level of impact based on project specifics and details concerning the affected properties.
- **Severe Impact:** Project-generated noise in this range is likely to cause a high level of community annoyance. The project sponsor should first evaluate alternative locations/alignments to determine whether it is feasible to avoid severe impacts altogether. If it is not practical to avoid severe impacts by changing the location of the project, mitigation measures must be considered.

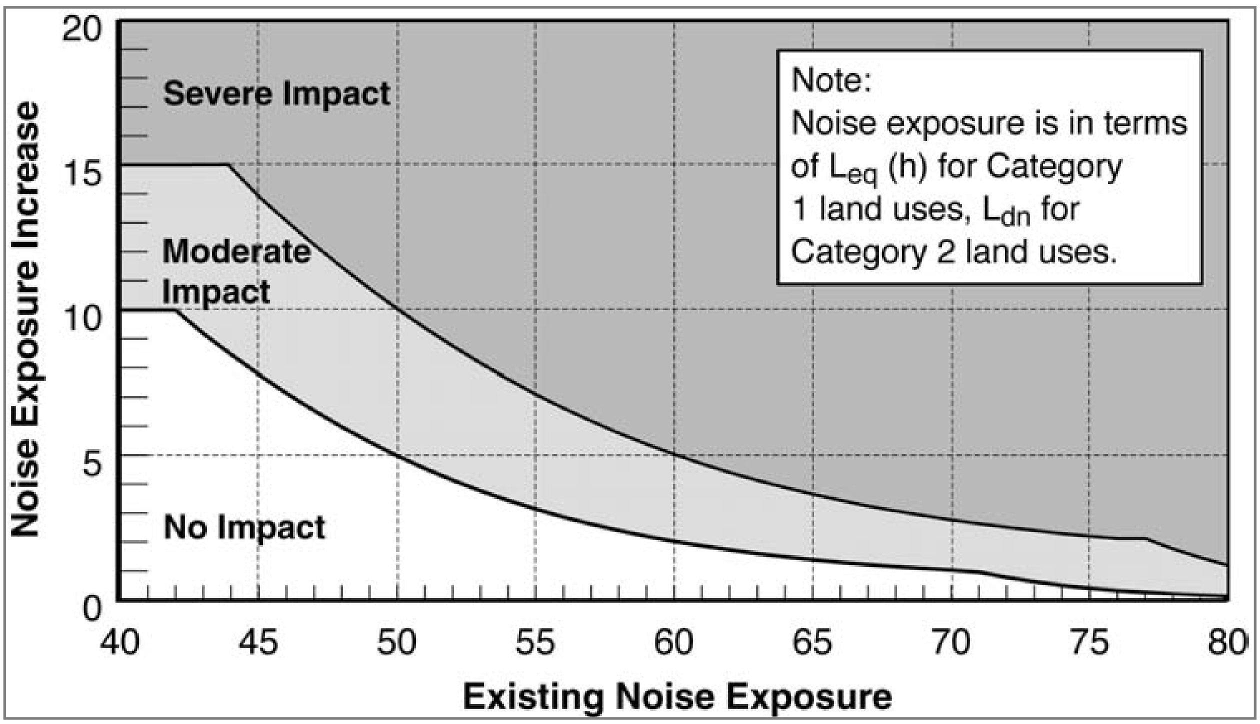
FIGURE 3-1. FTA NOISE IMPACT CRITERIA



Source: FTA, 2018

Although the curves in **Figure 3-1** are defined in terms of the project noise exposure and the existing noise exposure, the increase in the cumulative noise—when project-generated noise is added to existing noise levels—is the basis for the criteria. To illustrate this point, **Figure 3-2** shows the noise impact criteria for Category 1 and Category 2 land uses in terms of the allowable increase in the cumulative noise exposure. Because the Ldn and Leq are measures of total acoustic energy, any new noise source in a community will cause an increase, even if the new source level is lower than the existing level. In **Figure 3-2**, the criterion for a moderate impact allows a noise exposure increase of 10 dB if the existing noise exposure is 42 dBA or less, but only a 1 dB increase when the existing noise exposure is 70 dBA.

FIGURE 3-2. FTA CUMULATIVE NOISE IMPACT CRITERIA



Source: FTA, 2018

As the existing level of ambient noise increases, the allowable level of transit noise increases, but the total amount that community noise exposure is allowed to increase is reduced. This accounts for the unexpected result that a project noise exposure that is lower than the existing noise exposure can still cause an effect.

3.2 Operational Vibration Impact Criteria

The operational vibration impact criteria used for the Project are based on the information contained in Chapter 6 of the FTA noise and vibration guidance manual. The criteria for a general vibration assessment are based on land use and train frequency, as shown in **Table 3-2**. Some buildings, such as concert halls, recording studios and theaters, can have a higher sensitivity to vibration (or ground-borne noise) but do not fit into the three categories listed in **Table 3-2**. Because of the sensitivity of these buildings, special attention is paid to these buildings during the environmental assessment of a project. **Table 3-3** shows the FTA criteria for acceptable levels of vibration for several types of special buildings.

TABLE 3-2. GROUND-BORNE VIBRATION AND NOISE IMPACT CRITERIA FOR GENERAL ASSESSMENT

Land Use Category	Ground-Borne Vibration Impact Levels (VdB re 1 micro-inch /sec)			Ground-Borne Noise Impact Levels (dBA re 20 micro Pascals)		
	Frequent Events[a]	Occasional Events[b]	Infrequent Events[c]	Frequent Events[a]	Occasional Events[b]	Infrequent Events[c]
Category 1: Buildings where vibration would interfere with interior operations.	65[d]	65 [d]	65 [d]	N/A [e]	N/A [e]	N/A [e]
Category 2: Residences and buildings where people normally sleep.	72	75	80	35	38	43
Category 3: Institutional land uses with primarily daytime use.	75	78	83	40	43	48

Source: FTA, 2018

a "Frequent Events" is defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.

b "Occasional Events" is defined as between 30 and 70 vibration events of the same source per day. Most commuter trunk lines have this many operations.

c "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.

d This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Vibration-sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.

e Vibration-sensitive equipment is generally not sensitive to ground-borne noise.

TABLE 3-3. GROUND-BORNE VIBRATION AND NOISE CRITERIA FOR SPECIAL BUILDINGS

Type of Building or Room	Ground-Borne Vibration Impact Levels (VdB re 1 micro-inch /sec)		Ground-Borne Noise Impact Levels (dBA re 20 micro Pascals)	
	Frequent Events[a]	Occasional or Infrequent Events[b]	Frequent Events[a]	Occasional or Infrequent Events[b]
Concert Halls	65	65	25	25
TV Studios	65	65	25	25
Recording Studios	65	65	25	25
Auditoriums	72	80	30	38
Theaters	72	80	35	43

Source: FTA, 2018

a "Frequent Events" is defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.

b "Occasional or Infrequent Events" is defined as fewer than 70 vibration events per day. This category includes most commuter rail systems.

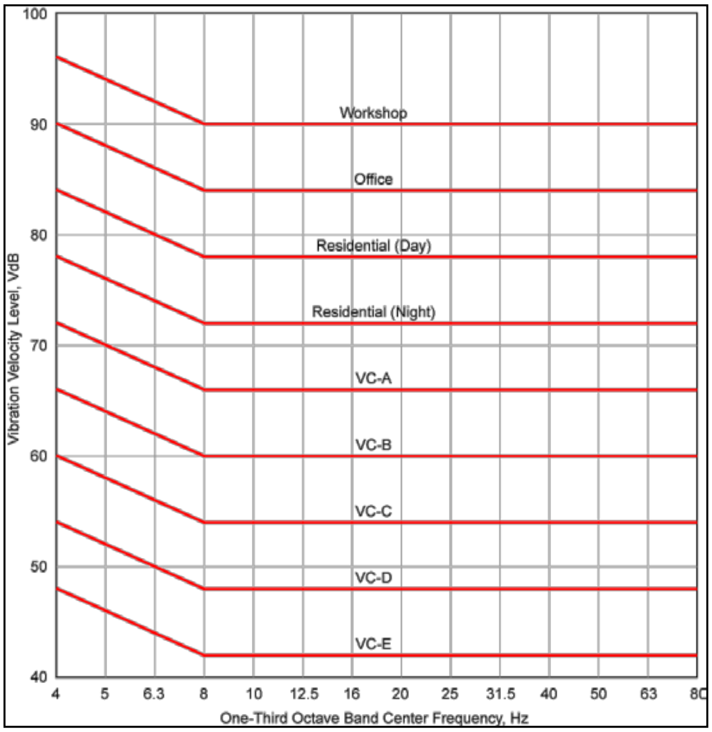
If the building will rarely be occupied when the trains are operating, there is no need to consider impact. As an example, consider locating a commuter rail line next to a concert hall. If no commuter trains will operate after 7 pm, it should be rare that the trains interfere with the use of the hall.

Table 3-2 and **Table 3-3** include additional criteria for ground-borne noise, which is a low-frequency noise that is radiated from the motion of room surfaces, such as walls and ceilings in buildings due to ground-borne vibration. Ground-borne noise is defined in terms of dBA, which emphasizes middle and high frequencies, which are more audible to human ears. The criteria for ground-borne noise are much lower than for airborne noise to account for the low-frequency character of ground-borne noise; however, because airborne noise typically masks ground-borne noise for above ground (at-grade or elevated) transit systems, ground-borne noise is only assessed for operations in tunnels, where airborne noise is not a factor, or at locations such as recording studios, which are well insulated from airborne noise.

The criteria for a detailed vibration assessment are shown in **Figure 3-3** and descriptions of the curves are shown in **Table 3-4**. The curves in **Figure 3-3** are applied to the projected vibration spectrum for the Project. If the vibration level at any one frequency exceeds the criteria, there is impact. Conversely, if the entire proposed vibration spectrum of the Project is below the curve, there will be no impact.

For the Project, the detailed vibration assessment criteria will be used to assess operational ground-borne vibration, except at special buildings where the general vibration assessment criteria will be used.

FIGURE 3-3. FTA DETAILED VIBRATION CRITERIA



Source: FTA, 2018

TABLE 3-4. INTERPRETATION OF VIBRATION CRITERIA FOR DETAILED ANALYSIS

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

* As measured in 1/3-octave bands of frequency over the frequency range 8 to 80 Hz.

Source: FTA, 2018

3.3 Construction Criteria

Construction activities associated with a large transportation project often generate noise and vibration complaints even though they only take place for a limited time. For the D2 Project, construction noise and vibration impacts are assessed where the exposure of noise- and vibration-sensitive receivers to construction-related noise or vibration is projected to occur at levels exceeding standards established by FTA and established thresholds for architectural and structural building damage (FTA, 2018).

3.3.1 Noise Impact

Table 3-5 shows the FTA construction noise criteria for a detailed analysis. The last column applies to construction activities that extend over 30 days near any given receiver. The Ldn is used to assess impacts in residential areas and 24-hr Leq is used in commercial and industrial areas. The 8-hr Leq and the 30-day average Ldn noise exposure from construction noise calculations use the noise emission levels of the construction equipment, their location, and operating hours. The construction noise limits are normally assessed at the noise-sensitive receiver property line.

TABLE 3-5. FTA CONSTRUCTION NOISE CRITERIA

Land Use	8-hour Leq, dBA		Noise Exposure, dBA
	Day	Night	30-day Average
Residential	80	70	75
Commercial	85	85	80*
Industrial	90	90	85*

* Use a 24-hour Leq instead of Ldn.

Source: FTA, 2018

3.3.2 Vibration Impact

In addition to the vibration criteria for human annoyance and interference with equipment and spaces described above, there are also vibration criteria for damage from construction activities. Typical transit operations do not have the potential for damage, so only certain construction activities are assessed for damage.

The thresholds for damage to structures are typically several orders of magnitude above the thresholds for human response to vibration. **Table 3-6** shows the FTA criteria for vibration damage to structures. This is based on the structure and construction type (and not a designation as historic). **Table 3-6** includes criteria in both VdB and Peak Particle Velocity (PPV).

TABLE 3-6. FTA CONSTRUCTION VIBRATION DAMAGE CRITERIA

Building Category	PPV (in/sec)	Approximate Lv*
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

* RMS velocity in VdB re 1 micro-inch/second
Source: FTA, 2018

4 Affected Environment

The affected noise and vibration environment along the D2 Subway alignment was investigated based on a review of current project and land use information, data from previous investigations, visual surveys and measurements conducted during September and December of 2018. A summary of noise and vibration sensitive land uses along the project alignment is provided below, followed by descriptions of the existing noise and vibration conditions in the project area.

4.1 Noise and Vibration Sensitive Land Use

Land use in the D2 study area includes a combination of residential, institutional and commercial zones. Noise-sensitive and vibration-sensitive land uses in the study area were identified based on alignment drawings, aerial photographs, visual surveys, and land use information. Sensitive receptors located along the LPA alignment include multi-family residences, hotels, courthouses, a museum, an aquarium, a school, a church, a medical office, a cultural center and a TV studio. Summary descriptions of noise and vibration sensitive land use along segments of the proposed alignment, from west to east, are provided below.

- Victory Development: Along this segment, the alignment travels from the existing light rail system down Museum Way at grade. Nearby noise and vibration sensitive receptors include the Arpeggio Victory Park Apartments, the Vista Apartments, the W Dallas Residences, the Northend Apartments and the SkyHouse Dallas Apartments, as well as the Perot Museum of Nature and Science.
- N Griffin Street: Along this segment, the alignment parallels N Griffin Street in subway. Nearby noise and vibration sensitive receptors include the Dallas World Aquarium, the Ross Apartments, the KDFW FOX TV studio, the Homewood Suites Hotel and the Crowne Plaza Hotel.
- Commerce Street: Along this segment, the alignment travels in subway below Commerce Street. Nearby noise and vibration receptors include the Earle Cabell Federal Building and Courthouse, the Metropolitan Condos, the Manor House Apartments, the Adolphus Hotel, the Magnolia Hotel, the Joule Hotel, the Dallas Power and Light Flats, the Hampton Inn Hotel, the Continental Apartments, the Merc Apartments, the Element Apartments, the Statler Residences, the UNT Dallas College of Law and the Dallas Municipal Court building.
- Commerce Street to IH-345: Along this segment, the alignment travels in subway with a potential open cut passenger station section located near a building with a medical office.
- IH-345 to N Good Latimer Expressway: Along this segment, the alignment parallels Swiss Avenue at grade before tying into the existing light rail system. There are a number of

noise and vibration sensitive receptors in the tie-in area, including the Elan City Lights Apartments, the Live Oak Lofts, the Latino Cultural Center, the St. James A.M.E. Temple Church, the Epic Deep Ellum mixed-use development and the Marquis on Gaston Apartments.

4.2 Existing Noise Conditions

Existing noise sources along the project alignment include roadway traffic, rail operations and local activities. The existing ambient sound levels vary by location, depending on the proximity to roads and other noise sources, and are generally typical of an urban environment. Existing ambient noise levels were characterized through direct measurements at representative sites in the study area during September and December of 2018.

4.2.1 Noise Measurement Locations and Procedures

The noise measurement programs consisted of both long-term (24-48 hour) and short-term (one-hour) monitoring of the A-weighted sound level. All of the measurement sites were selected to represent a range of existing noise conditions at noise-sensitive areas along the project alignment. For this study, long-term noise measurements were made at five sites (designated as LT-A through LT-E) and short-term noise measurements were made at three sites (designated as ST-A, ST-B and ST-C). The noise measurement locations are shown in **Figure 4-1** and photographs of these measurement sites are included in **Appendix A**.

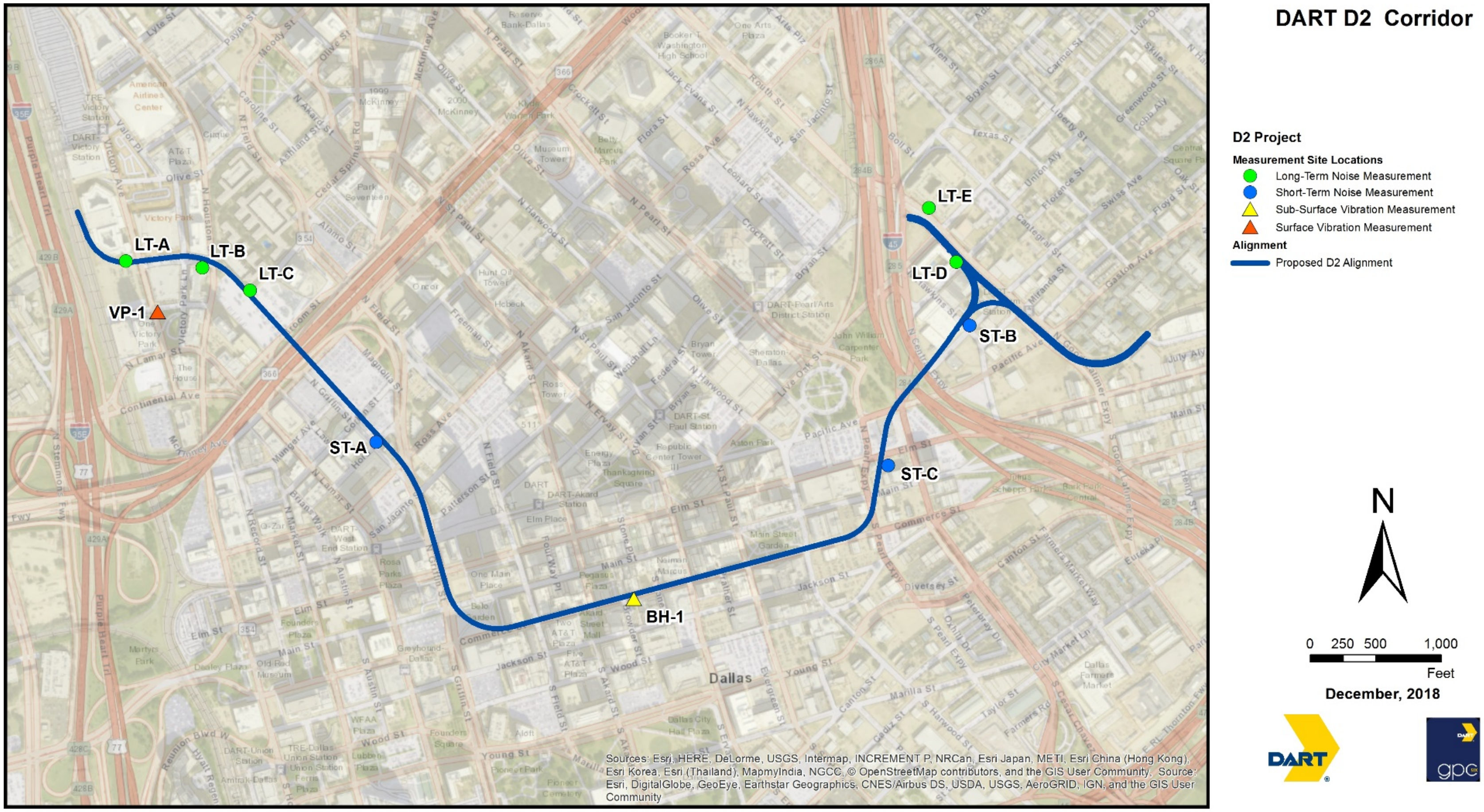
At each of the measurement sites, the A-weighted sound levels were continuously monitored during the measurement periods. The noise measurements were performed with NTi Audio model XL2 noise monitors that conform to American National Standards Institute (ANSI) Standard S1.4 for Type 1 (Precision) sound level meters. Calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST) were carried out in the field before and after each set of measurements using an acoustical calibrator.

In all cases, the measurement microphone was protected by a windscreen and supported on a tripod at a height of four to six feet above the ground and was positioned to characterize the exposure of the site to the dominant noise sources in the area. For example, microphones were located at the approximate setback lines of the receptors from adjacent roads, and were positioned to avoid acoustic shielding by landscaping, fences, or other obstructions.

4.2.2 Noise Measurement Results

The results of the existing ambient noise measurements are summarized in **Table 4-1** and detailed noise data are included in **Appendix B**. Overall, the results in **Table 4-1** serve as the basis for determining the existing noise conditions at all noise-sensitive receptors along the project alignment.

FIGURE 4-1. NOISE AND VIBRATION MEASUREMENT SITE LOCATIONS



Source: Cross-Spectrum Acoustics, 2019

TABLE 4-1. SUMMARY OF EXISTING AMBIENT NOISE MEASUREMENT RESULTS

Site No.	Measurement Location Description	Start of Measurement		Meas. Duration (hours)	Noise Exposure (dBA)	
		Date	Time		Ldn	Leq
LT-A	Arpeggio Victory Park Apartments 2425 Victory Avenue, Dallas	09/05/2018	09:15	48	68	63[1]
LT-B	The Vista Apartments 2345 N Houston Street, Dallas	09/05/2018	09:35	48	68	65[1]
LT-C	The Northend Apartments 2323 N Field Street, Dallas	09/05/2018	10:10	48	66	61[1]
LT-D	Live Oak Lofts 2502 Live Oak Street, Dallas	12/05/2018	15:00	24	74	69[1]
LT-E	Elan City Lights Apartments 2627 Live Oak Street, Dallas	12/05/2018	16:00	24	79	73[1]
ST-A	N Griffin Street and Hord Street, Dallas	09/06/2018	16:22	1	60[2]	62
ST-B	Swiss Avenue and Hawkins Street, Dallas	09/07/2018	09:05	1	63[2]	65
ST-C	2121 Main Street, Dallas	12/06/2018	11:40	1	61[2]	63

Source: Cross-Spectrum Acoustics, 2019

[1] Represents the average Leq measured during the peak transit hours (6 am to 9 am and 3 pm to 6 pm).
[2] The Leq measurement data were used to estimate the Ldn using FTA methodology. This approach tends to be conservative and to underestimate the existing noise levels, which can result in the assessment of higher levels of noise impact for a project.

The noise measurements at each monitoring site are described below:

Site LT-A: 2425 Victory Avenue, Dallas (Arpeggio Victory Apartments). The Ldn measured near the south fence line of this apartment building was 68 dBA, with an average Leq of 63 dBA measured during the peak transit hours. Noise sources affecting this location included traffic on I-35E and Victory Avenue, trains on the nearby rail corridor (TRE commuter, DART light rail and freight trains) and activity in the adjacent parking lot.

Site LT-B: 2345 N Houston Street, Dallas (The Vista Apartments). The Ldn measured on the second floor balcony of Unit #204 near the northeast corner of this apartment building was 68 dBA, with an average Leq of 65 dBA measured during the peak transit hours. Noise sources affecting this location included traffic on N Houston Street, aircraft operations and construction activity in the area.

Site LT-C: 2323 N Field Street, Dallas (The Northend Apartments). The Ldn measured inside the fence at the south corner of this apartment complex was 66 dBA, with an average Leq of 61 dBA measured during the peak transit hours. Noise sources affecting this location included traffic on the elevated Woodall Rodgers Freeway, aircraft operations, birds and activity in the adjacent parking lot.

Site LT-D: 2502 Live Oak Street, Dallas (Live Oak Lofts). The Ldn measured on the first floor landing of the stairway at the northeast corner of this condominium building was 74 dBA, with an average Leq of 69 dBA measured during the peak transit hours. Noise sources affecting this location included roadway traffic on N Good-Latimer Expressway, DART train operations and local resident activity. In 2011, DART installed an automatic lubricator at this location to address wheel squeal along the curve.

Site LT-E: 2627 Live Oak Street, Dallas (Elan City Lights Apartments). The Ldn measured on the balcony of a second floor residence at this apartment complex was 79 dBA, with an average Leq of 73 dBA measured during the peak transit hours. Noise sources affecting this location included roadway traffic on N Good-Latimer Expressway and elevated highway IH 345 as well as DART train operations (including train whistles and bells at the nearby grade crossing).

Site ST-A: N Griffin Street and Hord Street, Dallas. The one-hour Leq measured at this intersection, at the corner of a parking lot across from both the Dallas World Aquarium and Ross Apartments, was 62 dBA, with an estimated Ldn of 60 dBA. Noise sources affecting this location included traffic on N Griffin Street and nearby fire station activity.

Site ST-B: Swiss Avenue and Hawkins Street, Dallas. The one-hour Leq measured at the corner of a parking lot at this intersection was 65 dBA, with an estimated Ldn of 63 dBA. Noise sources affecting this location included traffic on IH 345, aircraft operations and building mechanical equipment.

Site ST-C: 2121 Main Street, Dallas. The one-hour Leq measured in the parking lot behind this building was 63 dBA, with an estimated Ldn of 61 dBA. Noise sources affecting this location included local street traffic, aircraft and distant light construction activity.

4.3 Existing Vibration Conditions

Vibration-sensitive land use along the project segments is essentially the same as the noise-sensitive land use, except for parks and other outdoor sites which are not considered vibration-sensitive. In addition, there is a vibration-sensitive TV studio along the alignment.

Existing vibration sources along the project alignment include auto, bus and truck traffic on local streets. However, vibrations from street traffic are not generally perceptible at receivers in the study area unless streets have significant bumps, potholes, or other uneven surfaces. The only significant sources of existing ground vibration along the LPA are existing train operations at each end of the alignment where it ties into the existing light rail system. Furthermore, the FTA vibration impact criteria are not ambient-based; that is, future project vibrations are not compared with existing vibrations to assess impacts. Therefore, the vibration measurements for the project focused on characterizing the soil conditions along the proposed alignments rather than on characterizing the existing vibration levels as described below.

4.3.1 Vibration Measurement Procedures and Equipment

Vibration propagation measurements were conducted in the study area during September 2018 to determine the vibration response characteristics of the ground near vibration-sensitive locations. The measurements included a surface test to characterize vibration propagation for at-grade train operation and a borehole test to characterize vibration propagation for subway operation.

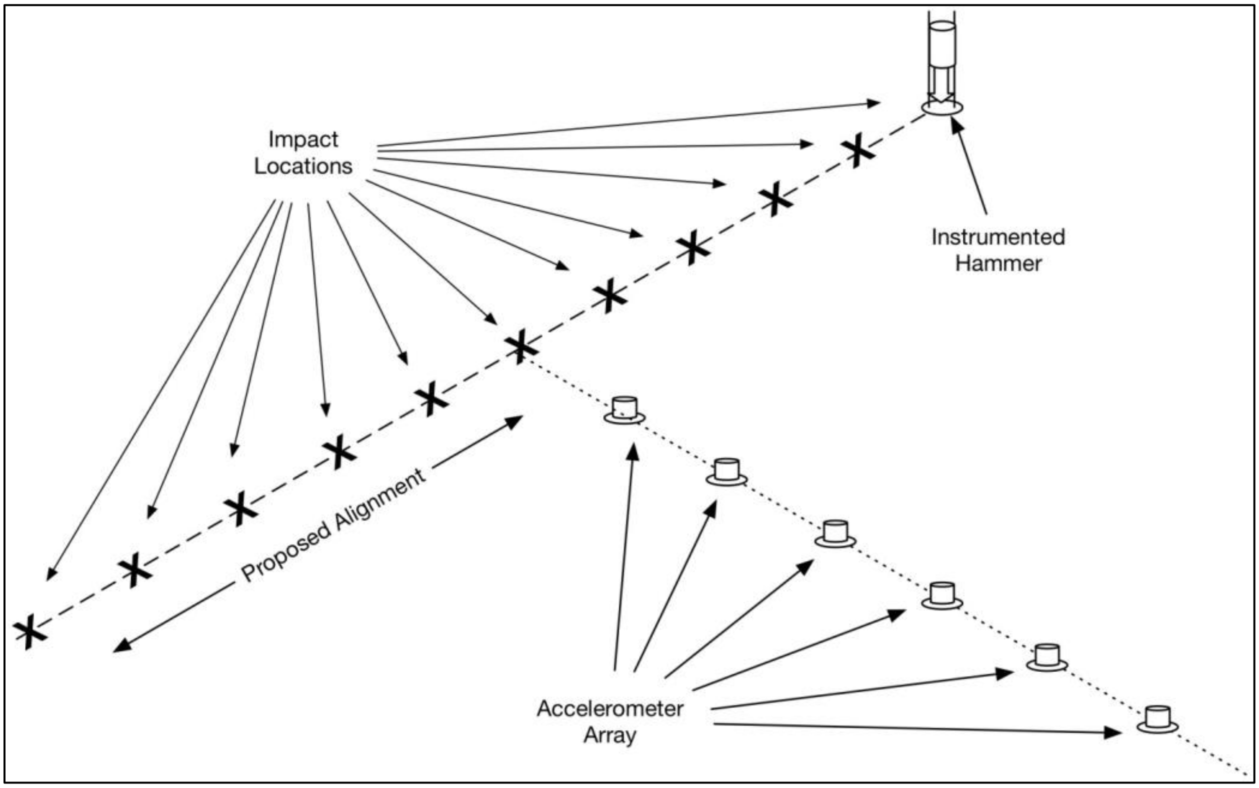
For the surface test, a custom-built instrumented hammer was used to impart an impulsive force to the ground. The magnitude of the force resulting from the acceleration and mass of the falling hammer was measured using a load cell, and the resulting vibration signals were measured using high-sensitivity accelerometers mounted in a vertical orientation on the ground. The signals from the load cell and accelerometers were recorded using Data Translation DT9837A digital acquisition hardware. Data Translation's QuickDAQ software, running on a laptop computer, was used to review the measurement data.

The surface vibration propagation test procedure is shown schematically in **Figure 4-2**. The instrumented hammer was used to generate impulses at specific locations spaced 15 feet apart along a line in the vicinity of the proposed alignment. A line of accelerometers was placed perpendicular to the line of impacts as shown in the figure. The relationship between the input force and the resulting vibration measured by the accelerometers, called the point source transfer mobility (PSTM), was calculated using proprietary software in the CSA laboratory. For application to an extended train, the line source transfer mobility (LSTM) was estimated using numerical integration of the PSTM data. The transfer mobility represents the vibration propagation characteristics of the ground at the measurement site and at other sites with similar geology.

For the borehole test, the hammer of a drilling rig was used to impart a force to the soil at the approximate future depth of the subway tunnel invert. The force was measured using a downhole load cell attached to the bottom end of the drill string, and the resulting vibration signals were measured using high-sensitivity accelerometers mounted in a vertical orientation on the ground surface. The signals from the load cell and accelerometers were recorded using Data Translation DT9837A digital acquisition hardware. Data Translation's QuickDAQ software, running on a laptop computer, was used to review the measurement data.

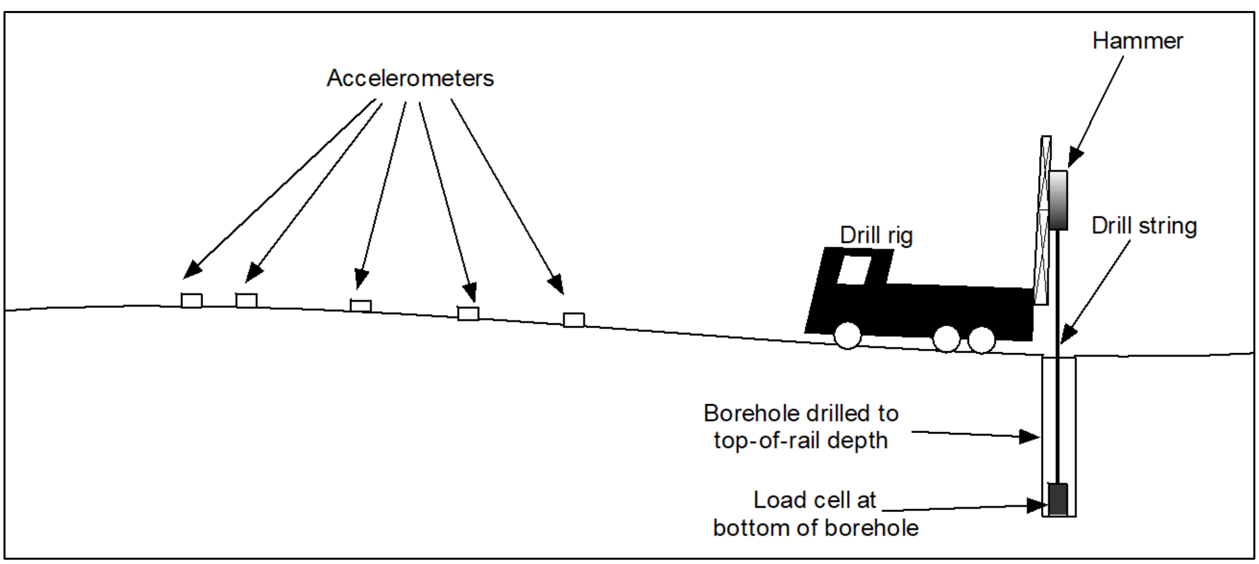
The borehole vibration propagation test procedure is shown schematically in **Figure 4-3**. The instrumented hammer was used to generate impulses at the bottom of the borehole, and a line of accelerometers was placed on the surface as shown in the figure. The PSTM was calculated using proprietary software in the Cross-Spectrum Acoustics (CSA) laboratory. For application to an extended train, the LSTM was estimated using numerical integration of the PSTM data.

FIGURE 4-2. SURFACE VIBRATION PROPAGATION MEASUREMENT SCHEMATIC



Source: Cross-Spectrum Acoustics, 2019

FIGURE 4-3. BOREHOLE VIBRATION PROPAGATION MEASUREMENT SCHEMATIC



Source: Cross-Spectrum Acoustics, 2019

4.3.2 Vibration Measurement Locations

Two representative vibration propagation test sites were selected for the measurements. These included one surface test site (VP-1) near an at-grade segment of the alignment and one borehole test site (BH-1) along a tunnel portion of the alignment. The locations of these sites are shown in **Figure 4-1** and site photographs are included in **Appendix A**. The test sites are described below.

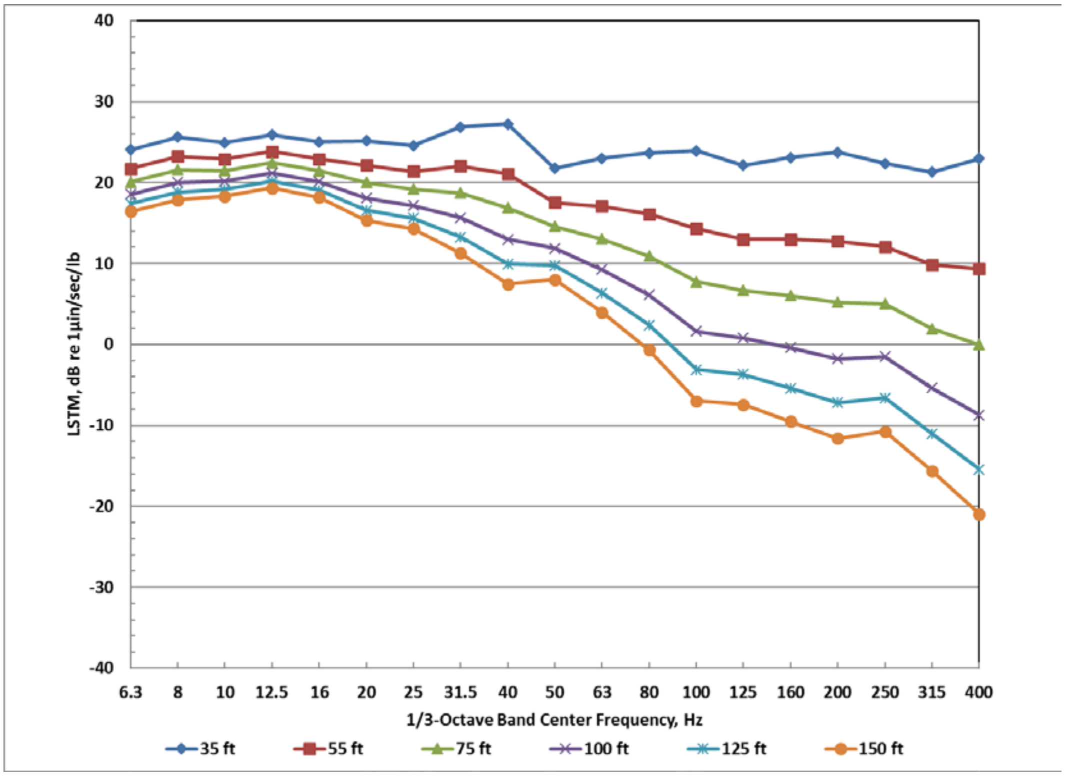
Site VP-1: Victory Avenue and High Market Street, Dallas. The surface vibration propagation measurement at this location was conducted at the southeast corner of this intersection, located one block south of the proposed at-grade alignment along Museum Way in the Victory Development area. For these tests, the impacts were generated at six points spaced 15 feet apart along the Victory Avenue sidewalk, extending to a distance of 75 feet south of the intersection. The resulting vibration signals were measured using accelerometers mounted vertically on the High Market Street sidewalk at six points located at distances ranging from 35 feet to 150 feet east of the intersection.

Site BH-1: Commerce Street (east of Browder Street), Dallas. The borehole vibration propagation measurement at this location was conducted along the proposed subway alignment on the south side of Commerce Street in downtown Dallas. Considering the proposed tunnel invert depth, the impacts were generated at borehole depths of 44 feet and 54 feet. The resulting vibration signals were measured using accelerometers mounted vertically on the ground in the Browder Street Mall at six points located between 15 feet and 115 feet from the borehole, and accelerometers mounted vertically on the Commerce Street sidewalk at six points located up to 120 feet east of the drill rig.

4.3.3 Vibration Measurement Results

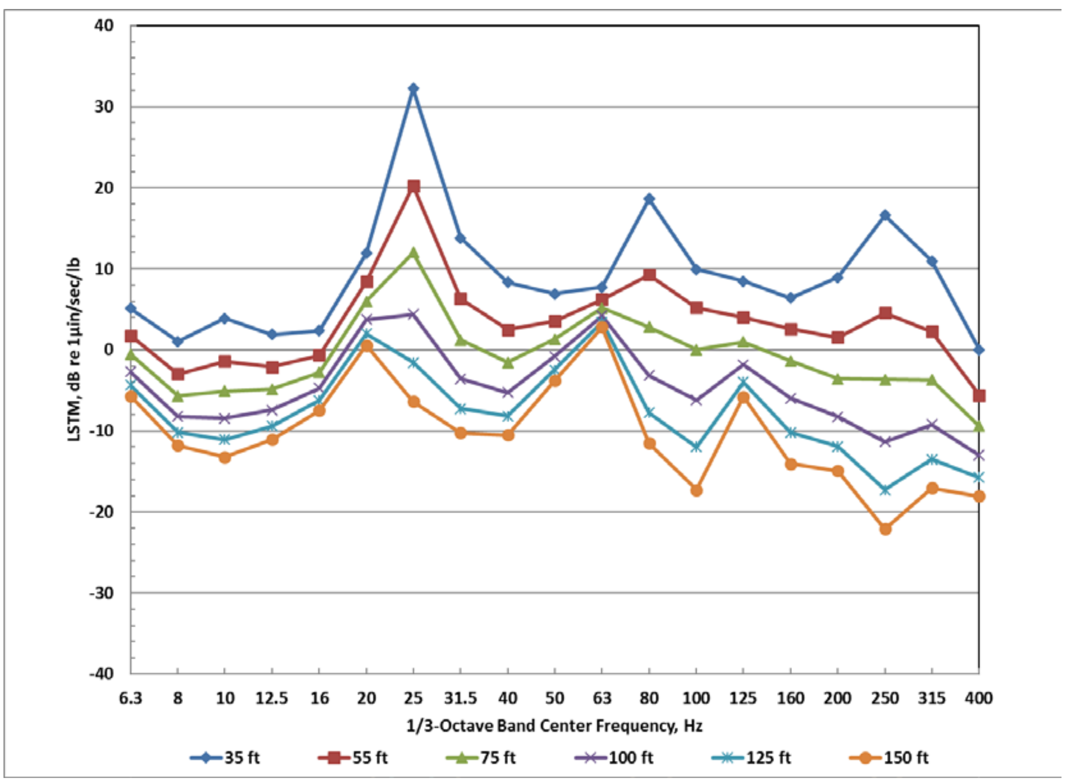
Results of the vibration propagation tests are shown in **Figure 4-4** for Site VP-1 and in **Figure 4-5** for Site BH-1. The results in these figures are provided in terms of the measured LSTM at a range of distances. Detailed vibration propagation data is provided in **Appendix C**.

FIGURE 4-4. VIBRATION PROPAGATION TEST DATA AT SITE VP-1



Source: Cross-Spectrum Acoustics, 2019

FIGURE 4-5. VIBRATION PROPAGATION TEST DATA AT SITE BH-1



Source: Cross-Spectrum Acoustics, 2019

5 Prediction Methodology

5.1 Airborne Noise Prediction

The primary component of wayside noise from the train operation is wheel/rail noise from the steel wheels rolling on steel rails. Secondary sources, such as vehicle air-conditioning and other ancillary equipment, will sometimes be audible and can also contribute to the overall train noise exposure at lower speeds. Noise levels were projected based on noise data for the DART low-floor Super Light Rail Vehicle (SLRV), the proposed project's operating plan and the prediction model specified in the FTA guidance manual. The D2 Subway Project operating plan has been revised from the 2010 AA/DEIS due to track geometry, vehicle upgrade, and revised peak headways. Significant factors are summarized below:

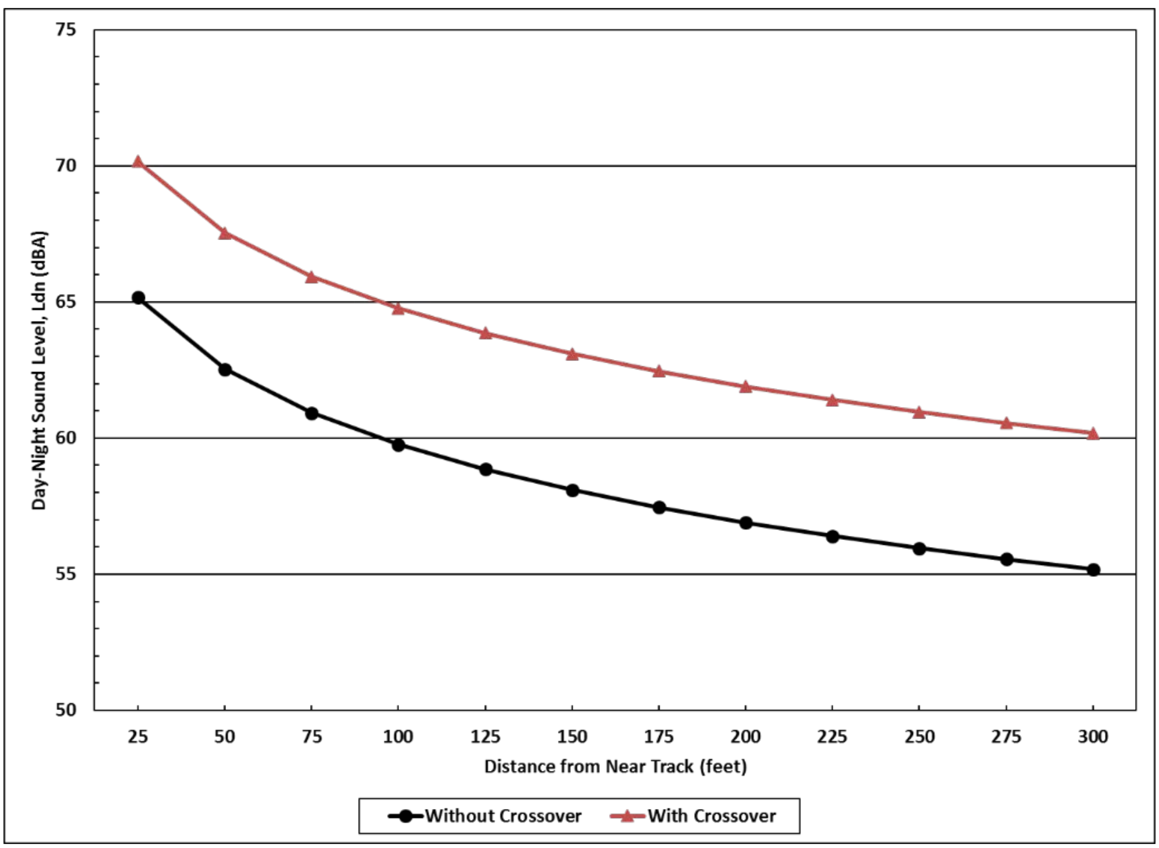
- Based on measurement data for a prototype DART low-floor SLRV (HMMH, 2006), the predictions assume that a single 124-foot-long vehicle operating at 50 mph on at-grade ballast and tie track with continuous welded rail (CWR) generates a Sound Exposure Level (SEL)[1] of 82 dBA at a distance of 50 feet from the track centerline. This value, which corresponds to a reference SEL value of 76 dBA at a speed of 25 mph, is consistent with the FTA reference SEL values for rail cars and streetcars.
- Based on FTA guidance, an adjustment of +3 dBA is applied to the noise computations in areas where the trains will be operating at grade on embedded or direct fixation track to account for the noise increase relative to operation on ballast and tie track.
- It is assumed that all trains will consist of three vehicles, although actual operations may have shorter trains depending on time of day.
- Based on the current DART Orange Line and Green Line weekday schedules, it is assumed that there will be 102 trains operating during the daytime hours (7 am to 10 pm) and 30 trains operating during the nighttime hours (10 pm to 7 am) in each direction. This schedule corresponds to a total of 264 trains passing by a given location during a 24-hour weekday period. Peak transit hour headways are assumed to be 15 minutes on each of the two lines, with eight trains per hour passing by in each direction.
- It is assumed that the above train volumes are reduced by one half beyond the Good-Latimer junction where Green Line trains turn south toward Baylor University Medical Center Station on the Southeast Corridor and where Orange Line trains turn north toward the Live Oak Lofts to the North Central Corridor.
- The maximum train operating speed is assumed to be 15 mph.

[1] The SEL describes a receiver's cumulative noise exposure from a single noise event. It is represented by the total A-weighted sound energy during the event, normalized to a one-second interval.

- Based on DART audible warning signal equipment and policy, train whistles are assumed to generate a sound level of 78 dBA at 50 feet from the track for a five-second period as trains approach gated grade crossings. It is assumed that the only gated crossings will be at Broome Street and McKinney Avenue and that traffic signals will be used at all other crossings without audible warning signals.
- Stationary warning bells, generating a sound level of 73 dBA at 50 feet, would be sounded at gated grade crossings before and after each train for a total duration of 30 seconds. It is assumed that only gated crossings will be at Broome Street and McKinney Avenue.
- Based on FTA guidance, wheel impacts at crossovers and turnouts are assumed to cause localized noise increases of 5 dBA within a distance of 300 feet.

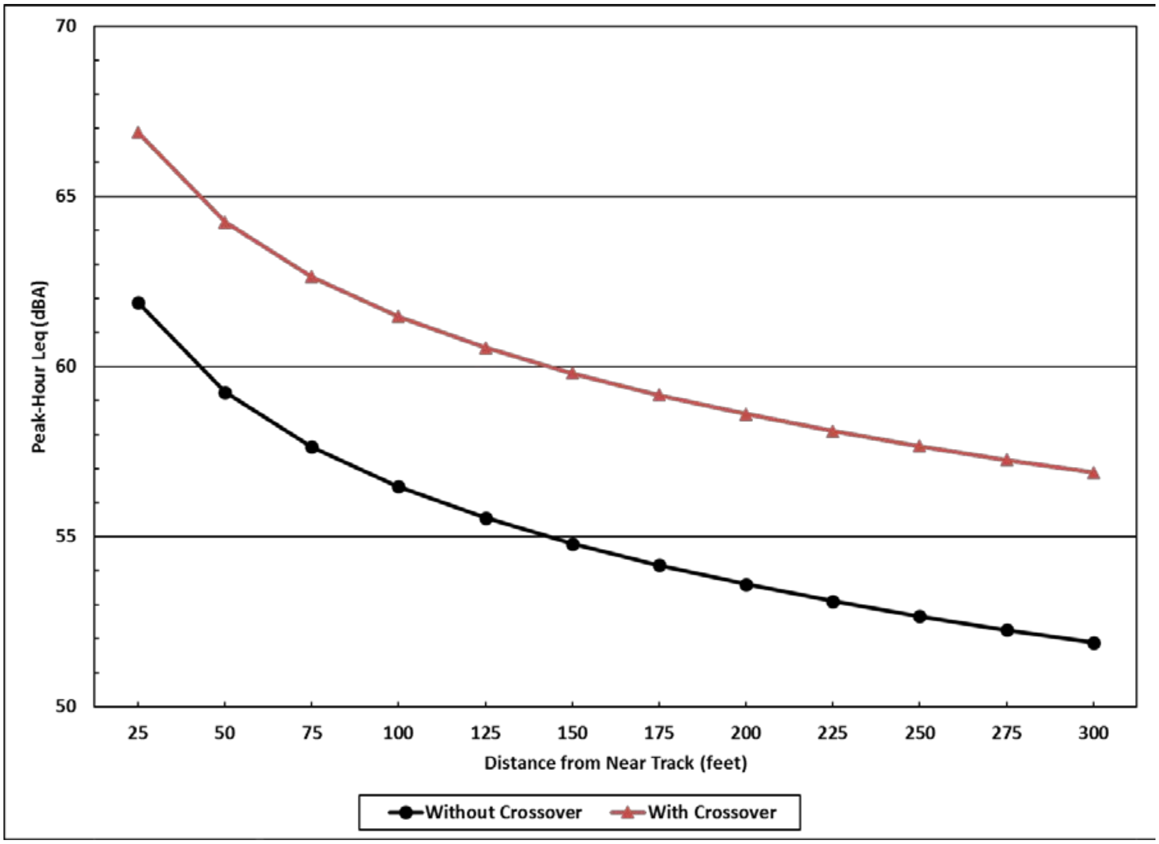
Examples of the projected unshielded weekday Ldn and peak-hour Leq from train operations on embedded track at 15 mph are shown in **Figure 5-1** and **Figure 5-2**, respectively, as a function of distance from the track centerline. In each figure, noise projections are provided for locations both with and without nearby crossovers.

FIGURE 5-1. PROJECTED 24-HOUR NOISE EXPOSURE FROM TRAIN OPERATIONS



Source: Cross-Spectrum Acoustics, 2019

FIGURE 5-2. PROJECTED PEAK TRANSIT HOUR NOISE EXPOSURE FROM TRAIN OPERATIONS



Source: Cross-Spectrum Acoustics, 2019

5.2 Ground-Borne Vibration Prediction

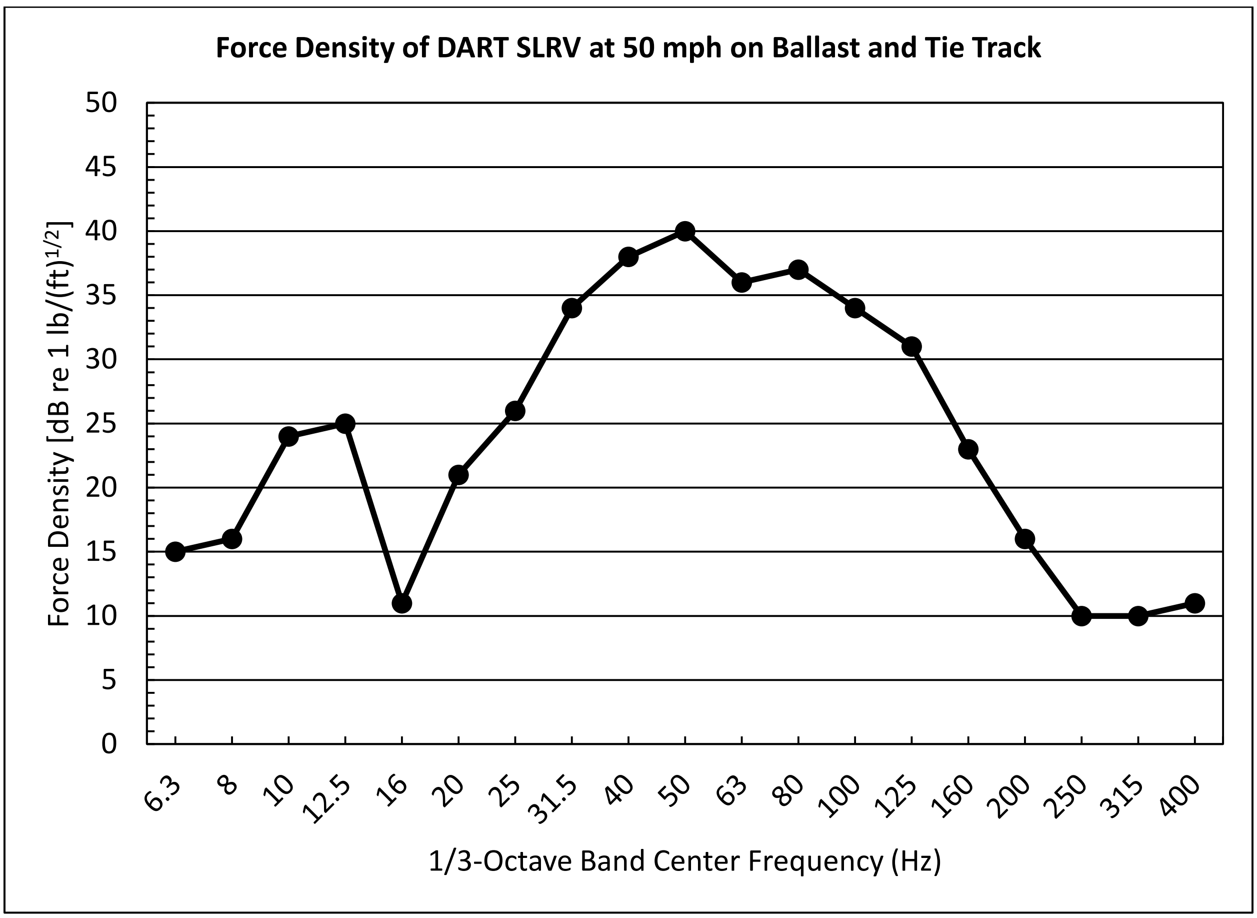
Projections of ground-borne vibration and ground-borne noise from train operations were carried out using the detailed vibration analysis procedures specified in the FTA guidance manual, based on the following factors:

- Vibration source level data for the DART vehicle operating at grade on ballast and tie track with continuous welded rail (CWR) were obtained from measurements conducted on a prototype DART low-floor SLRV (HMMH, 2006).
- The source level data was adjusted for speed and for embedded track conditions (where applicable) based on data from vibration measurements for the Central Corridor LRT Project (METRO Green Line) in Minneapolis-St. Paul, MN (ATS Consulting, 2008).
- Vibration propagation tests were conducted at two sites along the D2 alignment as described in Section 4.3. These tests measured the response of the ground to an input force. The results of these tests were combined with vibration source level data for the DART vehicle to project vibration levels from trains operating along the project corridor.
- The maximum train operating speed is assumed to be 15 mph.

- Based on FTA guidance, wheel impacts at track crossovers and turnouts are assumed to cause localized vibration increases of 10 VdB within a distance of 100 feet, and increases of 5 VdB at distances between 100 feet and 200 feet.
- The ground-to-building coupling loss (i.e. vibration reduction) is assumed to be 7 VdB for 1-2 story buildings and 10 VdB for taller buildings.
- A floor-to-floor attenuation (i.e. vibration reduction) of 2 VdB/floor is assumed.

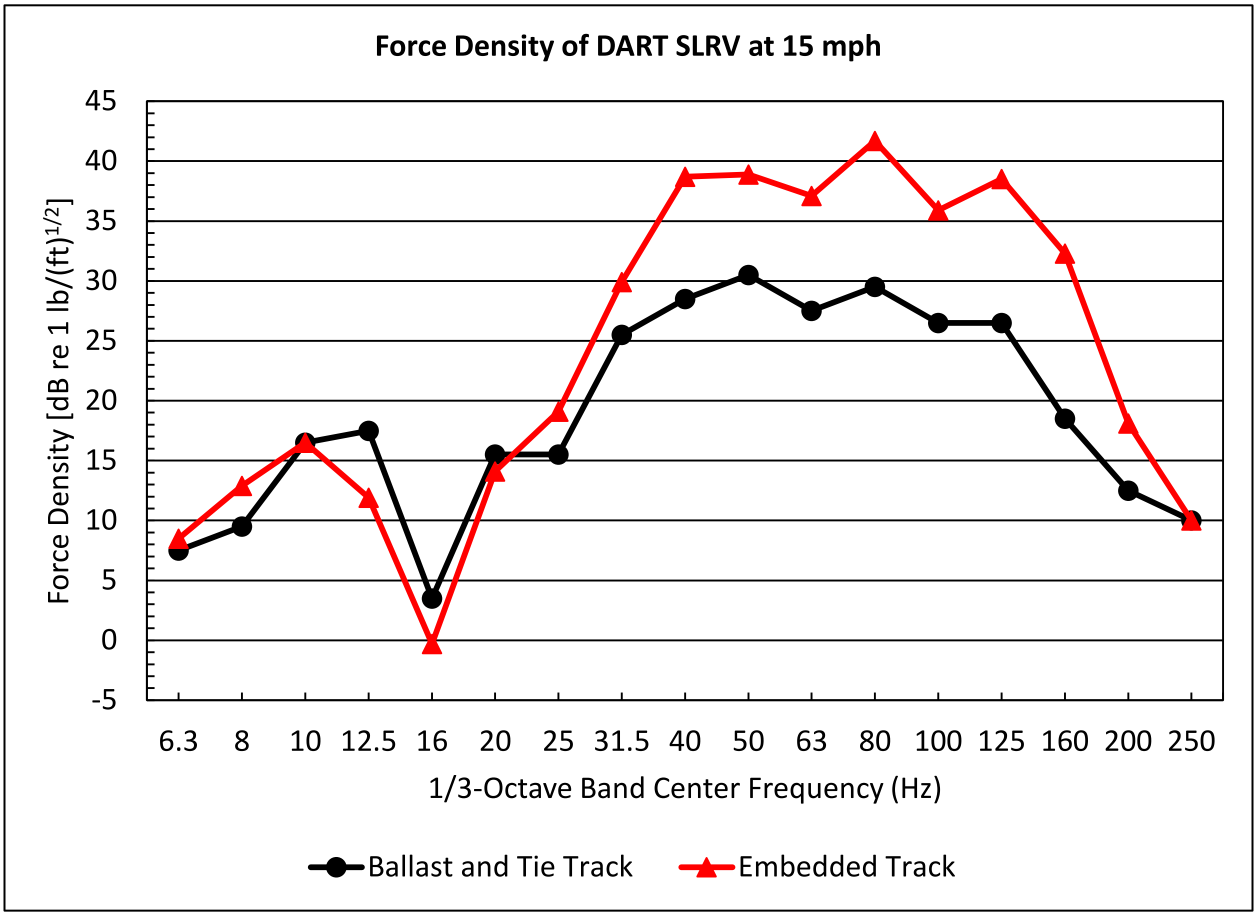
The DART SLRV vibration characteristics are represented by the force density level (FDL) spectrum shown in **Figure 5-3** below, measured for operation at 50 mph on ballast and tie track. This FDL spectrum was adjusted for speed and track configuration to estimate the FDL spectra for operation at 15 mph on ballast and tie or embedded track. The resulting FDL spectra, shown in **Figure 5-4**, indicate that vibration levels are projected to be about 10 dB higher at frequencies between 40 Hz and 160 Hz for SLRV operation on embedded track, relative to operation on ballast and tie track. These results were then combined with the ground vibration propagation test results (represented by the transfer mobility spectra shown in **Figure 4-4** and **Figure 4-5**) to project vibration levels as a function of distance for both surface and subway operation.

FIGURE 5-3. MEASURED DART SLRV FORCE DENSITY LEVEL SPECTRUM AT 50 MPH



Source: HMMH, 2006

FIGURE 5-4. ESTIMATED DART SLRV FORCE DENSITY LEVEL SPECTRA AT 15 MPH



Source: Cross-Spectrum Acoustics, 2019

5.3 Construction Noise and Vibration Prediction

5.3.1 Noise

Construction noise and impacts are assessed using a combination of the methods and construction source data contained in the FTA guidance manual and the FHWA Roadway Construction Noise Model (RCNM) from the *FHWA Construction Noise Handbook* (FHWA, 2006). Typical noise levels generated by representative pieces of equipment are listed in **Table 5-1**.

The noise exposure at a receiver location from the operation of a single piece of construction equipment may be calculated using the following equation:

$$Leq(n) = Lmax + 10 \times Log(U.F.) - 20 \times Log(D/50) - Ashielding$$

where:

Leq(n) = noise exposure at a receiver resulting from the operation of a single piece of equipment over n hours,

Lmax = noise emission level of the particular piece of equipment at the reference distance of 50 feet (taken from **Table 5-1**),

Ashielding = shielding provided by barriers, building, or terrain,

D = distance from the receiver to the piece of equipment in feet, and

U.F. = usage factor that accounts for the fraction of time that the equipment is in use over the specified time period. For Leq(1) assume a U.F. equal to 100% and for 8 hours or more use the values in **Table 5-1**.

The combination of noise from several pieces of equipment operating during the same time period is obtained from decibel addition of the Leq of each single piece of equipment calculated using the above equation.

TABLE 5-1. CONSTRUCTION EQUIPMENT NOISE EMISSION LEVELS

Equipment	Typical Noise Level (dBA) 50 ft from Source	Usage Factor (U.F), %
Air Compressor	80	40
Backhoe	80	40
Ballast Equalizer	82	50
Ballast Tamper	83	50
Compactor	82	20
Concrete Mixer	85	40
Concrete Pump	82	20
Crane, Derrick	88	16
Crane, Mobile	83	16
Dozer	85	16
Generator	82	50
Grader	85	40
Impact Wrench	85	50
Jack Hammer	88	20
Loader	80	40
Paver	85	50
Pile Driver (Impact)	101	20
Pile Driver (Vibratory)	95	20
Pneumatic Tool	85	50
Pump	77	50
Rail Saw	90	20
Rock Drill	85	20
Roller	85	20
Saw	76	20
Scarifier	83	20
Scraper	85	40
Shovel	82	40
Spike Driver	77	20
Tie Cutter	84	20
Tie Handler	80	20
Tie Inserter	85	20
Truck	84	40

TABLE 5-1. CONSTRUCTION EQUIPMENT NOISE EMISSION LEVELS

Equipment	Typical Noise Level (dBA) 50 ft from Source	Usage Factor (U.F), %

Source: FTA, 2018 and FHWA, 2006

5.3.2 Vibration

Construction vibration is assessed for areas where there is potential for impact from construction activities. Such activities include blasting, pile driving, demolition, drilling, excavation and tunneling in close proximity to sensitive structures. Typical vibration levels generated by representative pieces of equipment are listed in **Table 5-2**.

TABLE 5-2. CONSTRUCTION EQUIPMENT VIBRATION SOURCE LEVELS

Equipment		PPV at 25 ft (in/sec)	Approximate Lv[a] at 25 ft
Pile Driver (impact)	upper range	1.518	112
	typical	0.644	104
Pile Driver (vibratory)	upper range	0.734	105
	typical	0.170	93
Clam shovel drop (slurry wall)		0.202	94
Hydromill (slurry wall)	in soil	0.008	66
	in rock	0.017	75
Vibratory roller		0.210	94
Hoe ram		0.089	87
Large bulldozer		0.089	87
Caisson drilling		0.089	87
Loaded trucks		0.076	86
Jackhammer		0.035	79
Small bulldozer		0.003	58

Source: FTA, 2018

[a] RMS velocity in decibels (VdB) re 1 micro-inch/second

For damage assessment, the following equation is used:

PPVequip = PPVref × [(25/D)]^1.5

where:

PPVequip = the peak particle velocity in in/sec of the equipment adjusted for distance

PPVref = the reference vibration level in in/sec at 25 feet from **Table 5-2**, and

D = the distance from the equipment to the receiver in feet.

For annoyance assessment, the following equation is used:

Lv (D) = Lv (25 ft) - 30×Log(D/25)

where:

Lv(D) = RMS vibration level at distance D

Lv(25 ft) = RMS vibration level at 25 ft from **Table 5-2**, and

D = the distance from the equipment to the receiver in feet.

Although the method for tunnel construction has not yet been decided, the running tunnels for the DART D2 project can technically be excavated by tunnel boring machine (TBM) boring, roadheader excavation, or drill and blast excavation methods. Other than blasting, which may be restricted, TBM operations and the potential use of muck trains for spoils removal would be expected to generate the highest vibration levels.

Estimates of ground-borne vibration from TBM and muck train operations are based on measurements conducted of the Los Angeles Metro Red Line Section 2 construction near the Wilshire/Western Station (HMMH, 1993). The TBM in use during the measurements was a driven-shield type and the track system for the muck trains was directly attached to the concrete tunnel liner with no cross ties used to support the rails. The TBM measurements were performed at the ground surface at horizontal distances of 50 to 200 feet from the tunnel centerline and the top of the tunnel in this area was approximately 43 feet below the surface. The muck train measurements were made at horizontal distances of 0 to 170 feet from the tunnel centerline. **Figure 5-5** and **Figure 5-6** show the measured 1993 TBM and muck train vibration levels, respectively, in terms of the source to sensor slant distance.

To estimate TBM and muck train vibration levels, the 1993 measured reference levels at a known distance were extrapolated using the 2018 measured attenuation profiles from the borehole vibration propagation test performed in Dallas. The relation below was used to predict the RMS vibration velocity (Lv):

$Lv = Lv_0 + alpha \times log_{10}(D/D_0)$

where:

Lv = predicted ground vibration level, in VdB re 1 micro-in/sec

Lv_0 = 1993 measured reference RMS vibration velocity, in VdB re 1 micro-in/sec

D_0 = source to sensor distance for Lv_0, in feet

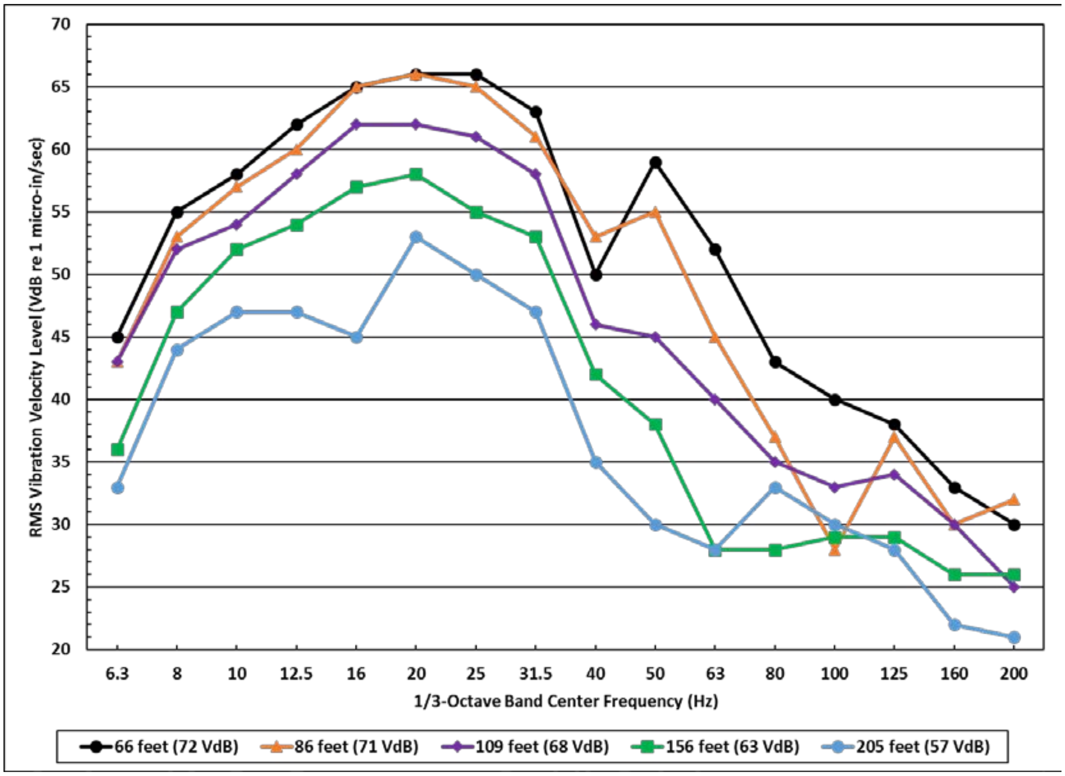
D = source to receiver distance for predicted level Lv, in feet

alpha = the slope of the measured transfer mobility (PSTM for TBM operations and LSTM for muck train operations)

Vibration levels were calculated for each 1/3-octave frequency band from 6.3 Hz to 200 Hz for the tunneling. For a given D the predicted level Lv was computed for each reference pair Lv_0 and D_0, and then a linear average was taken. Lastly, the overall vibration levels were obtained through a decibel sum across the bandwidth. **Figure 5-7** and **Figure 5-8** show the predicted ground vibration levels for TBM and muck train operations, respectively, at representative distances from the tunnel perimeter and tunnel invert, respectively.

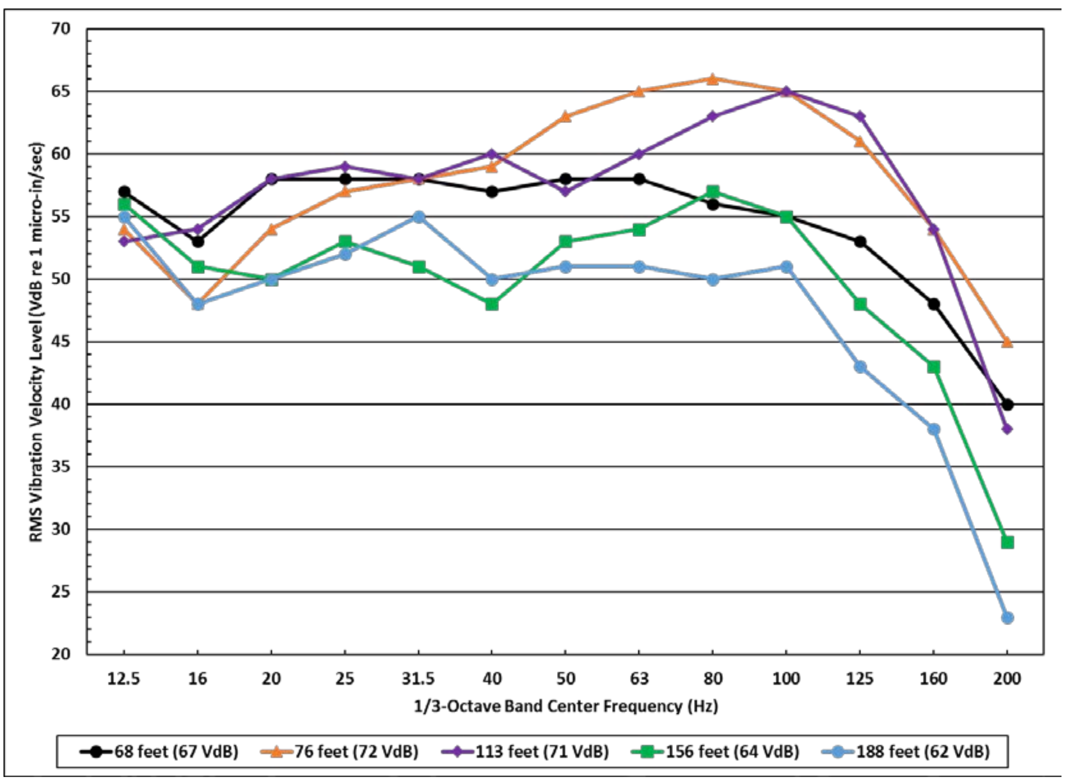
For predicting vibration from TBM and muck train operation in nearby buildings, the estimated ground vibration levels were adjusted for ground-to-building coupling loss (vibration reduction of 7 VdB for 1-2 story buildings and 10 VdB for taller buildings) and floor-to-floor attenuation (vibration reduction of 2 VdB/floor). In addition, a safety factor of +5 dB is also added to each one-third octave band to account for measurement uncertainties and other error sources in the prediction of vibration from these sources.

FIGURE 5-5. MEASURED TBM GROUND VIBRATION LEVELS



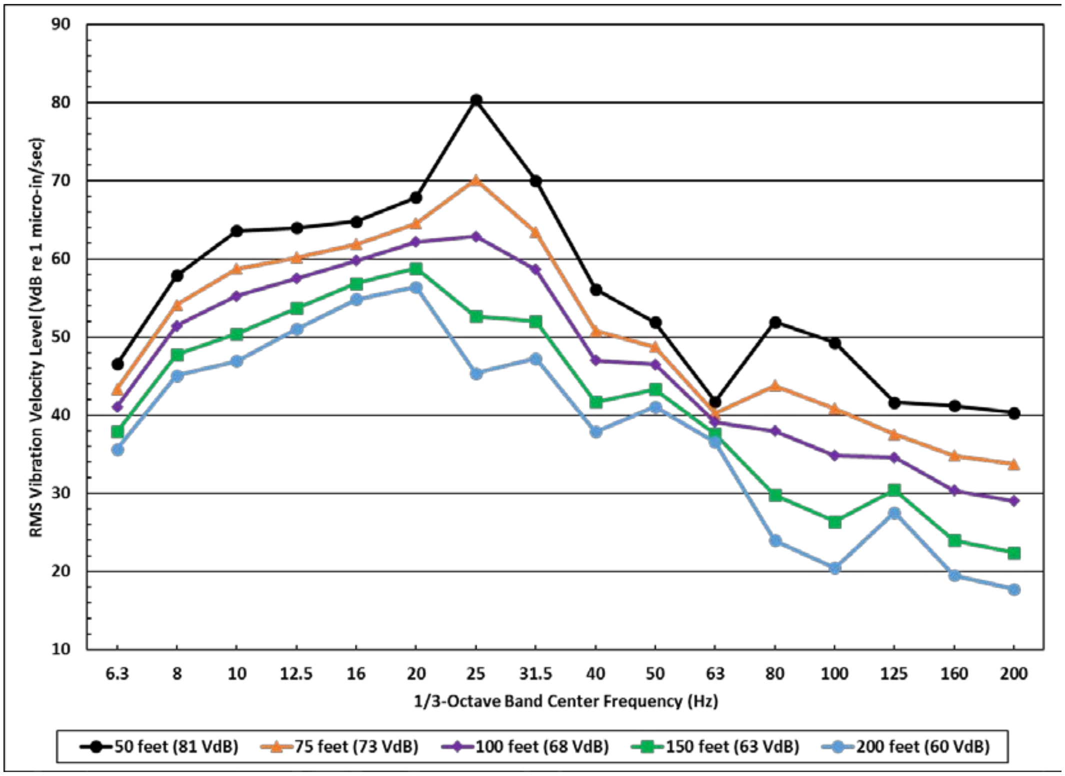
Source: HMMH, 1993

FIGURE 5-6. MEASURED MUCK TRAIN GROUND VIBRATION LEVELS



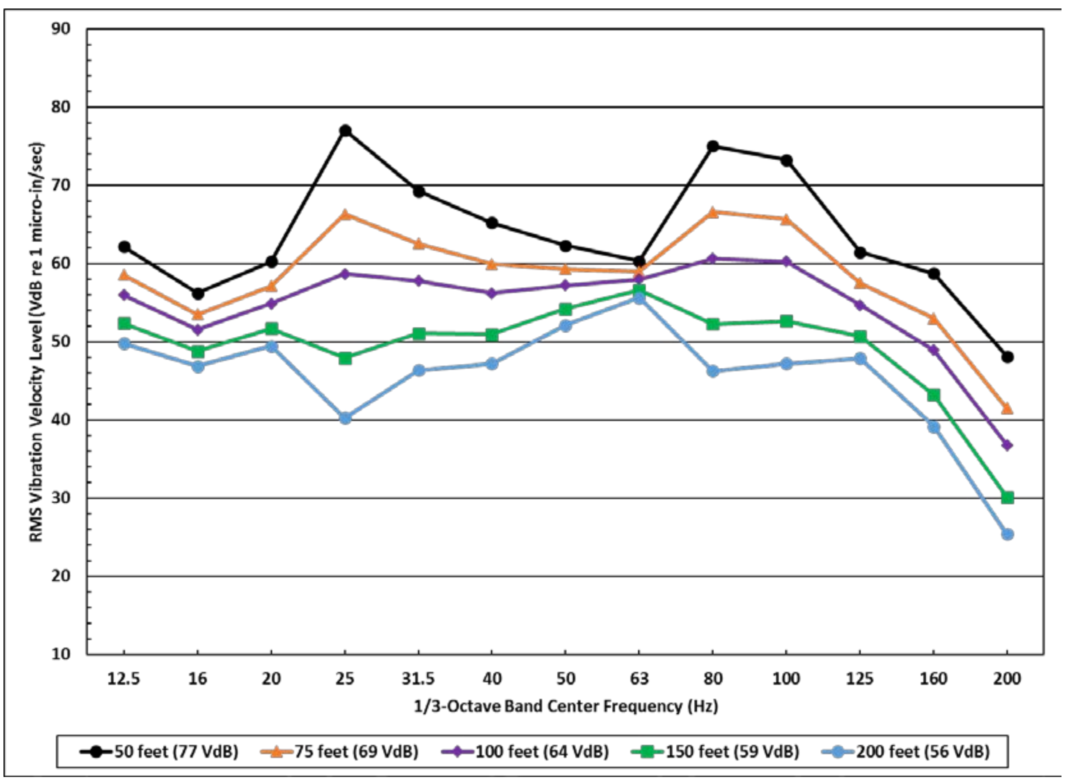
Source: HMMH, 1993

FIGURE 5-7. PREDICTED TBM GROUND VIBRATION LEVELS



Source: Cross-Spectrum Acoustics, 2019

FIGURE 5-8. PREDICTED MUCK TRAIN GROUND VIBRATION LEVELS



Source: Cross-Spectrum Acoustics, 2019

6 Environmental Consequences

Detailed noise and vibration impact assessments were carried out based on the criteria discussed in **Section 3** and the projections described in **Section 5**. The assessment results are presented below.

6.1 Operational Noise Impact Assessment

Comparisons of the existing and future noise levels are presented in **Table 6-1**, including results for FTA Category 2 (residential) receptors with both daytime and nighttime sensitivity to noise, and for FTA Category 3 (institutional) receptors with primarily daytime and evening use. In addition to the distances to the track and proposed train speeds, **Table 6-1** includes the existing noise levels, the projected noise levels from light rail operations, the predicted total noise levels and the projected noise increases due to the D2 Project. Based on a comparison of the predicted project noise levels with the impact criteria, the table also includes an inventory of the number of moderate and severe noise impacts for each noise-sensitive receiver.

The results in **Table 6-1** identify moderate noise impacts at an estimated total of 230 residences with projected noise increases of 1-2 decibels; no severe impacts are projected. The locations of the potential noise impacts are at four residential buildings as shown in **Figure 6-1** and **Figure 6-2**, including the W Dallas Residences, the Vista Apartments, the Northend Apartments and the Live Oak Lofts. With regard to the Live Oak Lofts, it should be noted that although the number of light rail trains passing by this location would be the same as today, additional noise impacts are projected due to the relocation of the tracks closer to the building and to the addition of a track crossover adjacent to the building.

Finally, there is the potential for additional noise impacts from wheel squeal at sensitive receptors near curves in at-grade portions of the D2 alignment. There is also the potential for additional noise impacts at locations above the subway portions of the alignment due to fan noise and train noise transmitted to the surface through ventilation shafts and gratings. Noise from these sources will be evaluated during project design when detailed information becomes available, and mitigation measures will then be developed as appropriate.

TABLE 6-1. SUMMARY OF NOISE IMPACTS WITHOUT MITIGATION

Noise-Sensitive Receiver Description	FTA Land Use Category	Side of Track[1]	Distance from Near Track (feet)	Train Speed (mph)	Existing Noise Level[2]	Project Noise Level[2]			Total Noise Level[2]	Noise Level Increase[2]	Number of Residential Impacts	
						Predicted[3]	Impact Criteria					
							Moderate	Severe			Moderate	Severe
Arpeggio Victory Park Apartments	2	NB	23	15	68	62	63	68	69	1.1	0	0
W Dallas Residences	2	NB	34	15	68	64	62	68	69	1.6	96	0
The Vista Apartments	2	SB	43	15	68	63	62	68	69	1.3	48	0
Northend Apartments	2	NB	35	15	66	64	61	66	68	2.3	32	0
Perot Museum of Nature and Science	3	NB	254	15	61	54	63	69	62	0.8	0	0
SkyHouse Dallas Apartments	2	SB	251	15	66	57	61	66	66	0.6	0	0
Dallas World Aquarium	3	SB	81	15	62	58	64	69	63	1.3	0	0
IPS Psychotherapist Office	3	SB	59	15	63	58	64	70	64	1.2	0	0
Elan City Lights Apartments	2	NE	94	15	79	60	65	75	79	0.1	0	0
Latino Cultural Center	3	NE	94	15	69	62	69	74	70	0.7	0	0
Live Oak Lofts	2	SW	18	15	74	66	65	72	75	0.7	54	0
St. James A.M.E. Temple	3	NE	87	15	69	62	69	74	70	0.8	0	0

TABLE 6-1. SUMMARY OF NOISE IMPACTS WITHOUT MITIGATION

Noise-Sensitive Receiver Description	FTA Land Use Category	Side of Track[1]	Distance from Near Track (feet)	Train Speed (mph)	Existing Noise Level[2]	Project Noise Level[2]			Total Noise Level[2]	Noise Level Increase[2]	Number of Residential Impacts	
						Predicted[3]	Impact Criteria				Moderate	Severe
							Moderate	Severe				
Epic Deep Ellum	2	SB	65	15	74	57	65	72	74	0.1	0	0
Marquis on Gaston Apartments	2	NB	71	15	74	57	65	72	74	0.1	0	0
TOTAL NUMBER OF NOISE IMPACTS:											**230**	**0**

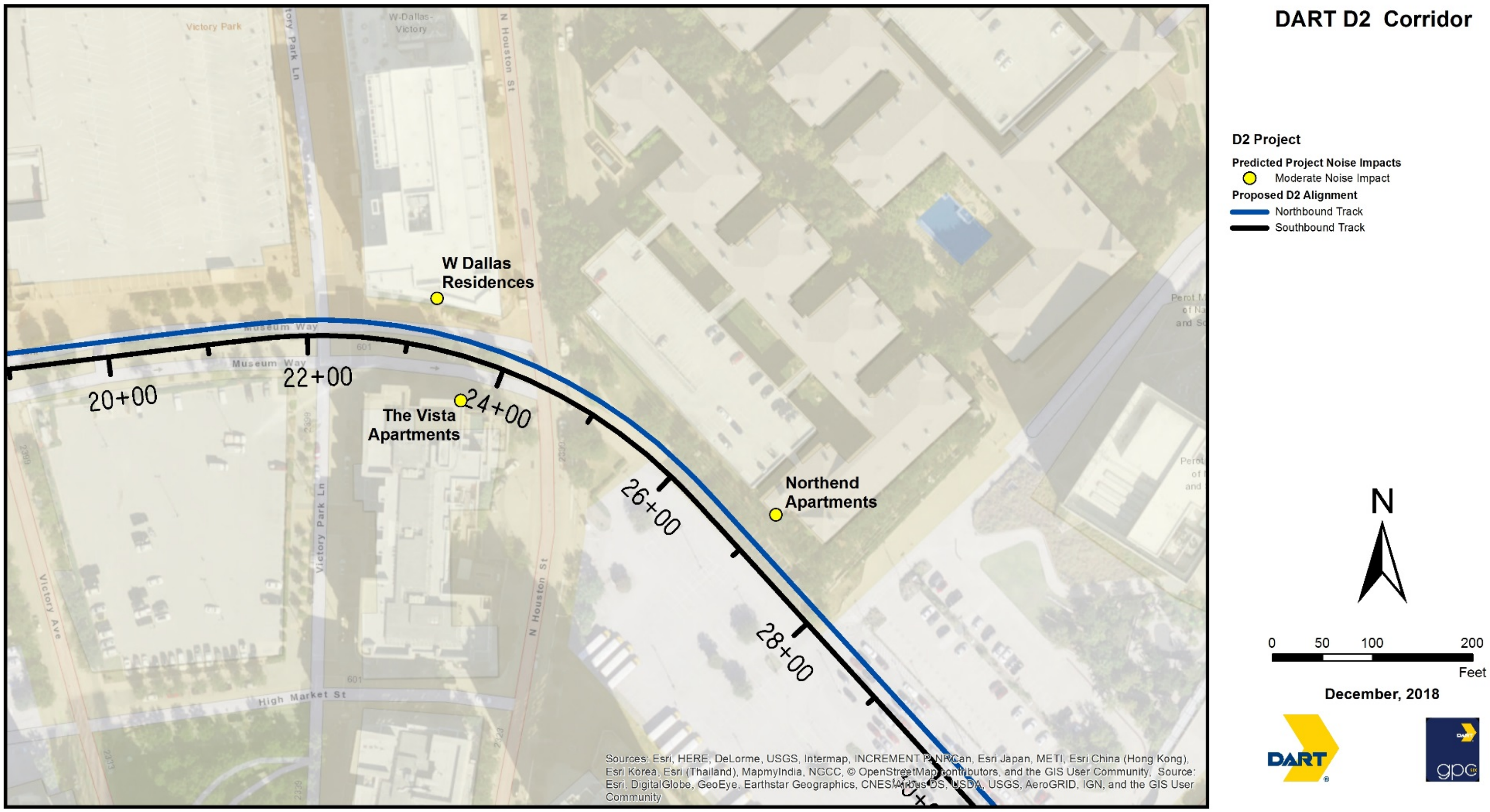
Source: Cross-Spectrum Acoustics, 2019

[1] Relative to track for trains in Northbound (NB) direction heading towards Victory Station or for trains in Southbound (SB) direction heading away from Victory Station; Northeast (NE) or Southwest (SW) side of track (relative to N Good Latimer Expressway).

[2] Noise levels are measured in dBA (rounded to the nearest decibel) and are based on Ldn for FTA Land Use Category 2 receivers and on Leq for FTA Land Use Category 3 receivers. For better resolution, noise level increases are shown to the nearest 0.1 decibel.

[3] Predicted levels include whistle and bell noise, where applicable (rounded to the nearest decibel).

FIGURE 6-1. NOISE IMPACT LOCATIONS WITHOUT MITIGATION (VICTORY DEVELOPMENT)



Source: Cross-Spectrum Acoustics, 2019

FIGURE 6-2. NOISE IMPACT LOCATIONS WITHOUT MITIGATION (DEEP ELLUM)

Source: Cross-Spectrum Acoustics, 2019

6.2 Operational Vibration Impacts Assessment

The approach used for assessing vibration impacts generally follows the approach used for noise impacts, except that existing vibration is typically not considered when evaluating impacts. For a detailed analysis, as was used for the D2 Project, the FTA impact threshold is 72 VdB for residential (Category 2) land use and 78 VdB for institutional (Category 3) land use, in terms of one-third octave band vibration velocity level. For special buildings (Category 1), the FTA impact threshold is 65 VdB in terms of overall vibration velocity level. The corresponding FTA ground-borne noise impact thresholds for frequent events (more than 70 train events per day) are 35 dBA for residential (Category 2) buildings, 40 dBA for institutional (Category 3) buildings and 25 dBA for special buildings (Category 1).

Table 6-2 provides an assessment of potential ground-borne vibration and noise impacts at sensitive receptors from light rail operations. The table includes the distance to the nearest track, the train speed, the impact criteria, and the projected future ground-borne vibration and noise levels. The results in **Table 6-2** identify ground-borne vibration impacts at 36 residences and ground-borne noise impacts at 54 residences, all at the Live Oak Lofts. These potential impacts are due to the close proximity of this building to the tracks as they are proposed to be shifted closer to the building, and associated crossover. The location of these impacts is shown in **Figure 6-3**.

6.3 Construction Noise and Vibration Impact Assessment

Temporary noise and vibration impacts could result from activities associated with utility relocation, grading, excavation, tunneling, track work, demolition, and installation of systems components. Such impacts may occur at noise-sensitive land use located within several hundred feet of the rail alignment. The potential for noise impacts would be greatest at locations near pavement breaking, and at locations close to any nighttime construction work. The potential for vibration impacts would be greatest at locations close to tunneling and vibratory compaction operations.

Although the method for tunnel construction has not yet been decided, the running tunnels for the DART D2 project can technically be excavated by TBM boring, roadheader excavation, or drill and blast excavation methods. Other than blasting, which may be restricted, TBM operations and the potential use of muck trains for spoils removal would be expected to generate the highest vibration levels.

Table 6-3 provides an assessment of potential ground-borne vibration and noise impacts at sensitive receptors from TBM operations. The results in this table indicate that there is the potential for ground-borne vibration impacts at the KDFW FOX4 TV Studio. Otherwise, no ground-borne vibration or ground-borne noise impacts are anticipated due to TBM operations. In addition, all of the projected vibration levels from TBM operations are well below the most stringent FTA damage criteria for buildings that are extremely susceptible to vibration damage.

Table 6-4 provides an assessment of potential ground-borne vibration and noise impacts at sensitive receptors from muck train operations. The results in this table indicate that there is the potential for ground-borne vibration impacts at the KDFW FOX4 TV Studio. In addition, 173 ground-borne noise impacts are anticipated due to muck train operations, including nearly all of the sensitive buildings adjacent to the proposed tunnel. However, all of the projected vibration levels from muck train operations are well below the most stringent FTA damage criteria for buildings that are extremely susceptible to vibration damage.

A quantitative assessment of construction noise and vibration impacts from tunneling and other activities will be conducted during the design phase of the Project when detailed construction scenarios are available. In particular, potential construction-related impacts to historic/special structures will be considered in final design.

TABLE 6-2. SUMMARY OF GROUND-BORNE VIBRATION AND NOISE IMPACTS WITHOUT MITIGATION

Noise-Sensitive Receiver Description	Side of Track[1]	Distance from Near Track (feet)	Train Speed (mph)	Ground-Borne Vibration[3]			Ground-Borne Noise[3]		
				Predicted GBV Level (VdB)[2]	GBV Impact Criterion (VdB)[2]	Number of GBV Impacts	Predicted GBN Level (dBA)[5]	GBN Impact Criterion (dBA)[5]	Number of GBN Impacts
Arpeggio Victory Park Apartments	NB	23	15	51	72	0	31	35	0
W Dallas Residences	NB	34	15	47	72	0	25	35	0
The Vista Apartments	SB	43	15	51	72	0	28	35	0
Northend Apartments	NB	35	15	56	72	0	35	35	0
Perot Museum of Nature and Science	NB	254	15	32	78	0	1	40	0
SkyHouse Dallas Apartments	SB	251	15	32	72	0	1	35	0
Dallas World Aquarium	SB	83	15	44	78	0	18	40	0
Ross Apartments	SB	81	15	33	72	0	11	35	0
KDFW FOX4 TV Studio	NB	108	15	38[4]	65[4]	0	11	25	0
Crowne Plaza Dallas Downtown	SB	69	15	34	72	0	11	35	0
Homewood Suites by Hilton Dallas	NB	113	15	29	72	0	5	35	0
Earle Cabell Federal Building and Courthouse	SB	82	15	33	78	0	11	40	0
Metropolitan Condos	NB	72	15	34	72	0	11	35	0
Manor House Apartments	SB	71	15	34	72	0	11	35	0

TABLE 6-2. SUMMARY OF GROUND-BORNE VIBRATION AND NOISE IMPACTS WITHOUT MITIGATION

Noise-Sensitive Receiver Description	Side of Track[1]	Distance from Near Track (feet)	Train Speed (mph)	Ground-Borne Vibration[3]			Ground-Borne Noise[3]		
				Predicted GBV Level (VdB)[2]	GBV Impact Criterion (VdB)[2]	Number of GBV Impacts	Predicted GBN Level (dBA)[5]	GBN Impact Criterion (dBA)[5]	Number of GBN Impacts
The Adolphus Hotel	NB	71	15	34	72	0	11	35	0
The Magnolia Hotel	NB	69	15	34	72	0	11	35	0
The Joule Hotel	NB	138	15	28	72	0	3	35	0
Dallas Power and Light Flats	SB	78	15	32	72	0	10	35	0
The Merc Apartments	NB	68	15	45	72	0	22	35	0
Hampton Inn Dallas Downtown	SB	68	15	40	72	0	17	35	0
The Element Apartments	NB	153	15	33	72	0	7	35	0
The Continental Apartments	SB	72	15	43	72	0	21	35	0
The Statler Residences	SB	71	15	34	72	0	11	35	0
UNT Dallas College of Law	NB	64	15	38	78	0	15	40	0
Dallas Municipal Court	NB	58	15	40	78	0	16	40	0
IPS Psychotherapist Office	SB	65	15	38	78	0	15	40	0
Elan City Lights Apartments	NE	94	15	43	72	0	16	35	0
Latino Cultural Center	NE	94	15	48	78	0	21	40	0

TABLE 6-2. SUMMARY OF GROUND-BORNE VIBRATION AND NOISE IMPACTS WITHOUT MITIGATION

Noise-Sensitive Receiver Description	Side of Track[1]	Distance from Near Track (feet)	Train Speed (mph)	Ground-Borne Vibration[3]			Ground-Borne Noise[3]		
				Predicted GBV Level (VdB)[2]	GBV Impact Criterion (VdB)[2]	Number of GBV Impacts	Predicted GBN Level (dBA)[5]	GBN Impact Criterion (dBA)[5]	Number of GBN Impacts
Live Oak Lofts	SW	18	15	75	72	36	55	35	54
St. James A.M.E. Temple	NE	87	15	49	78	0	22	40	0
Epic Deep Ellum	SB	65	15	48	72	0	22	35	0
Marquis on Gaston Apartments	NB	71	15	46	72	0	21	35	0
TOTAL NUMBER OF IMPACTS					**GBV:**	**36**		**GBN:**	**54**

Source: Cross-Spectrum Acoustics, 2019

[1] Relative to track for trains in Northbound (NB) direction heading towards Victory Station or for trains in Southbound (SB) direction heading away from Victory Station; Northeast (NE) or Southwest (SW) side of track (relative to N Good Latimer Expressway).

[2] Maximum one-third octave frequency band ground-borne vibration velocity level, measured in VdB referenced to 1 µin/sec (rounded to the nearest decibel).

[3] The predicted vibration and noise levels assume a ground-to-building vibration coupling loss of 7 VdB for 1-2 story buildings and 10 VdB for taller buildings.

[4] This is a FTA Land Use Category 1 receiver and the level represents the overall ground-borne vibration velocity level, measured in VdB referenced to 1 µin/sec (rounded to the nearest decibel). The ground-borne vibration impact criterion for FTA Land Use Category 1 receivers is based on the overall vibration level and is specific to the type of building. The ground-borne vibration impact criterion for TV studios is 65 VdB.

[5] Maximum overall ground-borne noise level, measured in dBA referenced to 20µPa.

FIGURE 6-3. GROUND-BORNE VIBRATION AND NOISE IMPACT LOCATION

Source: Cross-Spectrum Acoustics, 2019

TABLE 6-3. SUMMARY OF GROUND-BORNE VIBRATION AND NOISE ASSESSMENT FOR TBM OPERATIONS

Noise-Sensitive Receiver Description	Side of Track[1]	Slant Distance from Tunnel Perimeter (feet)	Ground-Borne Vibration[3]			Ground-Borne Noise[3]		
			Predicted GBV Level (VdB)[2]	GBV Impact Criterion (VdB)[2]	Number of GBV Impacts	Predicted GBN Level (dBA)[5]	GBN Impact Criterion (dBA)[5]	Number of GBN Impacts
Ross Apartments	SB	70	67	72	0	23	35	0
KDFW FOX4 TV Studio	NB	95	68[4]	65[4]	1	23	25	0
Crowne Plaza Dallas Downtown	SB	51	70	72	0	25	35	0
Homewood Suites by Hilton Dallas	NB	100	59	72	0	17	35	0
Earle Cabell Federal Building and Courthouse	SB	65	69	78	0	24	40	0
Metropolitan Condos	NB	54	69	72	0	24	35	0
Manor House Apartments	SB	53	69	72	0	24	35	0
The Adolphus Hotel	NB	53	69	72	0	24	35	0
The Magnolia Hotel	NB	51	70	72	0	25	35	0
The Joule Hotel	NB	126	54	72	0	13	35	0
Dallas Power and Light Flats	SB	62	67	72	0	23	35	0
The Merc Apartments	NB	49	70	72	0	25	35	0
Hampton Inn Dallas Downtown	SB	50	70	72	0	25	35	0
The Element Apartments	NB	141	53	72	0	11	35	0

TABLE 6-3. SUMMARY OF GROUND-BORNE VIBRATION AND NOISE ASSESSMENT FOR TBM OPERATIONS

Noise-Sensitive Receiver Description	Side of Track[1]	Slant Distance from Tunnel Perimeter (feet)	Ground-Borne Vibration[3]			Ground-Borne Noise[3]		
			Predicted GBV Level (VdB)[2]	GBV Impact Criterion (VdB)[2]	Number of GBV Impacts	Predicted GBN Level (dBA)[5]	GBN Impact Criterion (dBA)[5]	Number of GBN Impacts
The Continental Apartments	SB	54	69	72	0	24	35	0
The Statler Residences	SB	53	69	72	0	24	35	0
UNT Dallas College of Law	NB	47	73	78	0	27	40	0
Dallas Municipal Court	NB	42	74	78	0	28	40	0
TOTAL NUMBER OF IMPACTS				**GBV:**	**1**		**GBN:**	**0**

Source: Cross-Spectrum Acoustics, 2019

[1] Relative to track for trains in Northbound (NB) direction heading towards Victory Station or for trains in Southbound (SB) direction heading away from Victory Station; Northeast (NE) or Southwest (SW) side of track (relative to N Good Latimer Expressway).

[2] Maximum one-third octave frequency band ground-borne vibration velocity level, measured in VdB referenced to 1 µin/sec (rounded to the nearest decibel).

[3] The predicted vibration levels assume a ground-to-building coupling loss of 7 VdB for 1-2 story buildings and 10 VdB for taller buildings.

[4] This is a FTA Land Use Category 1 receiver and the level represents the overall ground-borne vibration velocity level, measured in VdB referenced to 1 µin/sec (rounded to the nearest decibel). The ground-borne vibration impact criterion for FTA Land Use Category 1 receivers is based on the overall vibration level and is specific to the type of building. The ground-borne vibration impact criterion for TV studios is 65 VdB.

[5] Maximum overall ground-borne noise level, measure in dBA referenced to 20µPa.

TABLE 6-4. SUMMARY OF GROUND-BORNE VIBRATION AND NOISE ASSESSMENT FOR MUCK TRAIN OPERATIONS

Noise-Sensitive Receiver Description	Side of Track[1]	Slant Distance from Track (feet)	Ground-Borne Vibration[3]			Ground-Borne Noise[3]		
			Predicted GBV Level (VdB)[2]	GBV Impact Criterion (VdB)[2]	Number of GBV Impacts	Predicted GBN Level (dBA)[5]	GBN Impact Criterion (dBA)[5]	Number of GBN Impacts
Ross Apartments	SB	81	61	72	0	40	35	24
KDFW FOX4 TV Studio	NB	108	67[4]	65[4]	1	39	25	1
Crowne Plaza Dallas Downtown	SB	69	62	72	0	40	35	1
Homewood Suites by Hilton Dallas	NB	113	53	72	0	33	35	0
Earle Cabell Federal Building and Courthouse	SB	82	61	78	0	40	40	0
Metropolitan Condos	NB	72	61	72	0	39	35	33
Manor House Apartments	SB	71	61	72	0	39	35	18
The Adolphus Hotel	NB	71	61	72	0	39	35	1
The Magnolia Hotel	NB	69	62	72	0	40	35	1
The Joule Hotel	NB	138	50	72	0	30	35	0
Dallas Power and Light Flats	SB	78	60	72	0	38	35	16
The Merc Apartments	NB	68	62	72	0	40	35	12
Hampton Inn Dallas Downtown	SB	68	62	72	0	40	35	1
The Element Apartments	NB	153	50	72	0	28	35	0

TABLE 6-4. SUMMARY OF GROUND-BORNE VIBRATION AND NOISE ASSESSMENT FOR MUCK TRAIN OPERATIONS

Noise-Sensitive Receiver Description	Side of Track[1]	Slant Distance from Track (feet)	Ground-Borne Vibration[3]			Ground-Borne Noise[3]		
			Predicted GBV Level (VdB)[2]	GBV Impact Criterion (VdB)[2]	Number of GBV Impacts	Predicted GBN Level (dBA)[5]	GBN Impact Criterion (dBA)[5]	Number of GBN Impacts
The Continental Apartments	SB	72	61	72	0	39	35	27
The Statler Residences	SB	71	61	72	0	39	35	36
UNT Dallas College of Law	NB	64	65	78	0	42	40	1
Dallas Municipal Court	NB	58	67	78	0	43	40	1
TOTAL NUMBER OF IMPACTS				**GBV:**	**1**		**GBN:**	**173**

Source: Cross-Spectrum Acoustics, 2019

[1] Relative to track for trains in Northbound (NB) direction heading towards Victory Station or for trains in Southbound (SB) direction heading away from Victory Station; Northeast (NE) or Southwest (SW) side of track (relative to N Good Latimer Expressway).

[2] Maximum one-third octave frequency band ground-borne vibration velocity level, measured in VdB referenced to 1 µin/sec (rounded to the nearest decibel).

[3] The predicted vibration levels assume a ground-to-building coupling loss of 7 VdB for 1-2 story buildings and 10 VdB for taller buildings.

[4] This is a FTA Land Use Category 1 receiver and the level represents the overall ground-borne vibration velocity level, measured in VdB referenced to 1 µin/sec (rounded to the nearest decibel). The ground-borne vibration impact criterion for FTA Land Use Category 1 receivers is based on the overall vibration level and is specific to the type of building. The ground-borne vibration impact criterion for TV studios is 65 VdB.

[5] Maximum overall ground-borne noise level, measure in dBA referenced to 20µPa.

7 Mitigation

7.1 Operational Noise Impact Mitigation

Potential mitigation measures for reducing noise impacts are described below:

- **Noise Barriers:** Installation of noise barriers beside the tracks is commonly used to reduce noise from surface transportation sources, although they may not be appropriate for an urban downtown area. Depending on the height and location relative to the tracks, noise barriers can achieve between 5 and 15 dB of noise reduction. The primary requirements for an effective noise barrier are that (1) the barrier must be high enough and long enough to break the line-of-sight between the sound source and the receiver, (2) the barrier must be of an impervious material with a minimum surface density of 4 lb./sq. ft., and (3) the barrier must not have any gaps or holes between the panels or at the bottom. Because many materials meet these requirements, the selection of materials for noise barriers is usually dictated by aesthetics, durability, cost, and maintenance considerations. Noise barriers for transit projects typically range in height from eight to twelve feet and costs range from $25 to $35 per square foot.
- **Building Sound Insulation:** Sound insulation of residences and institutional buildings can be implemented to improve the outdoor-to-indoor noise reduction. Although this approach has no effect on noise in exterior areas, it may be the best choice for sites where noise barriers are not feasible or desirable and for buildings where indoor sensitivity is of most concern. Substantial improvements in building sound insulation (on the order of 5 to 10 dBA) can often be achieved by adding an extra layer of glazing to the windows, by sealing holes in exterior surfaces that act as sound leaks, and by providing forced ventilation and air-conditioning so that windows do not need to be opened. Sound insulation typically ranges in cost per home from $25,000 to $50,000; the cost to insulate units in multi-family buildings would typically be lower.
- **Wheel/Rail Lubrication:** There are several options to mitigate potential wheel squeal from small-radius curves, including on-board solid-stick rail lubrication and wayside rail lubrication. Automated wayside top of rail friction modifier systems put a small amount of lubricant onto the top of the rail, which maintains a constant coefficient of friction. This type of lubricant has been shown to reduce or eliminate the potential for wheel squeal. The typical cost for this measure is $15,000 per track ($30,000 for both tracks). This type of wayside system was installed next to Live Oaks Lofts in 2011.
- **Special Trackwork:** Because the impacts of rail vehicle wheels over rail gaps at track turnout locations increase airborne noise by about five dBA close to the track, turnouts are a major source of noise impact when they are located in sensitive areas. If turnouts cannot be relocated away from sensitive areas, other noise control measures can be used such as the use of spring-rail, flange-bearing, or moveable-point frogs in place of

standard rigid frogs at turnouts. These devices allow the flangeway gap to remain closed in the main traffic direction for revenue service trains. Spring frogs typically cost $24,000 per frog while moveable point frogs cost approximately $140,000 per frog.

FTA states that, in determining the need for noise mitigation, severe impacts should be mitigated unless there are no practical means to do so. At the moderate impact level, more discretion should be used, and other project-specific factors should be included in the consideration of mitigation. These other factors can include the predicted increase over existing noise levels, the types and number of noise-sensitive land uses affected, existing outdoor-to-indoor sound insulation and the cost-effectiveness of mitigating noise to more acceptable levels. Consistent with DART policy, noise mitigation for moderate noise impacts is warranted at locations where a noise exposure increase of three (3) decibels or more is projected.

As described above in **Section 6.1**, the results of the noise impact assessment project an estimated total of 230 moderate noise impacts from light rail operation, including residential units at the W Dallas Residences, the Vista Apartments, the Northend Apartments and the Live Oak Lofts. Because the noise increases are projected to be less than 3 dB at all of these locations, noise mitigation is not required based on DART policy. However, there is the potential for noise impacts from wheel squeal at sensitive receptors near curves in the D2 alignment and therefore wheel/rail lubrication measures should be considered at such locations. These locations include through Victory and at the new connection with Good-Latimer tracks.

7.2 Operational Vibration Impact Mitigation

The vibration assessment assumes that the rail vehicle wheels and track are maintained in good condition with regular wheel truing and rail grinding. Beyond this, there are several approaches to reduce ground-borne vibration and ground-borne noise from train operation, as follows:

- **Ballast Mats:** A ballast mat consists of a pad made of rubber or rubber-like material placed on an asphalt or concrete base with the normal ballast, ties, and rail on top. The reduction in ground-borne vibration provided by a ballast mat is strongly dependent on the vibration frequency content and the design and support of the mat. The typical cost per track foot is $320.
- **Tire Derived Aggregate (TDA):** Also known as shredded tires, a typical TDA installation consists of an underlayment of 12 inches of nominally 3-inch size tire shreds or chips wrapped with filter fabric, covered with 12 inches of sub-ballast and 12 inches of ballast above that to the base of the ties. Tests suggest that the vibration attenuation properties of this treatment are midway between that of ballast mats and floating slab track. This low-cost option has been installed on two U.S. light rail transit systems (San Jose and Denver) for a number of years and test results have shown this treatment to be very effective at frequencies above about 25 Hz. The typical cost per track foot is $260.

- **Floating Slabs:** Floating slabs consist of thick concrete slabs supported by resilient pads on a concrete foundation; the tracks are mounted on top of the floating slab. Most successful floating slab installations are in subways, and their use for at-grade track is less common. Although floating slabs are designed to provide vibration reduction at lower frequencies than ballast mats, they are extremely expensive. The typical cost per track foot is $800.
- **Resiliently Supported Concrete Ties (Under-Tie Pads):** This treatment involves a special soft rubber pad embedded in the base of a concrete tie. The pad serves two purposes: (1) it provides a pliable surface to help anchor the ties on ballast; and (2) it provides vibration isolation between the tie and the ballast. This relatively simple treatment has been used extensively in Europe. Test results have shown this treatment to be very effective at frequencies above about 25 Hz and its cost is about 1.2 times the cost of a standard concrete tie. The typical cost per track foot is $260.
- **Resilient Rail Fasteners:** Resilient fasteners can be used to provide vibration isolation between rails and ties, as well as on concrete slabs for direct fixation track on aerial structures or in tunnels. These fasteners include a soft, resilient element to provide greater vibration isolation than standard rail fasteners in the vertical direction. Resilient rail fasteners are effective at frequencies above about 40 Hz. The typical cost per track foot is $360.
- **Special Trackwork:** Because the impacts of vehicle wheels over rail gaps at track turnout locations increases ground-borne vibration by up to 10 VdB close to the track, turnouts are a major source of vibration impact when they are located in sensitive areas. If turnouts cannot be relocated away from sensitive areas, another approach is to use spring-rail, flange-bearing or moveable-point frogs in place of standard rigid frogs at turnouts. These devices allow the flangeway gap to remain closed in the main traffic direction for revenue service trains. Spring frogs typically cost $24,000 per frog while moveable-point frogs cost approximately $140,000 per frog.

Vibration impacts that exceed FTA criteria are considered to be significant and to warrant mitigation, if reasonable and feasible. The results of the vibration impact assessment in **Section 6.2** predicted ground-borne vibration impact at 36 residences and ground-borne noise impact at 54 residences at the Live Oak Lofts that need to be evaluated for mitigation. Because the nearby crossover is expected to be a major source of vibration at this building, it is recommended that special frogs be considered for this crossover. Given that the track is embedded at this location, flange-bearing frogs may be the most practical measure.

Although the use of special frogs could eliminate the vibration impact at the Live Oak Lofts, this measure would not be sufficient to eliminate the ground-borne noise impact. Therefore, some type of resilient track support should also be considered at this location. However, it is recommended that a more detailed vibration analysis, including ground-to-building vibration propagation testing, be conducted at this site during project design to make a final determination regarding impact and any required mitigation.

7.3 Construction Noise and Vibration Impact Mitigation

Construction activities will be carried out in compliance with DART specifications and all applicable local noise regulations. In addition, the following mitigation measures will be applied as needed to minimize temporary construction noise and vibration impacts:

- Avoiding nighttime construction in residential neighborhoods;
- Locating stationary construction equipment as far as possible from noise-sensitive sites;
- Constructing noise barriers, such as temporary walls or piles of excavated material, between noisy activities and noise-sensitive receivers;
- Routing construction-related truck traffic to roadways that will cause the least disturbance to residents; and
- Using alternative construction methods to minimize the use of impact and vibratory equipment (e.g., pile-drivers and compactors).

Specific construction noise and vibration mitigation measures will be developed during the design phase of the Project when more detailed construction information is available, and requirements for noise and vibration monitoring will be evaluated at that time.

7.3.1 Blasting Mitigation

Due to the close proximity of buildings and historic structures to the project alignment, there is a significant potential for vibration impacts from blasting. Therefore, it is recommended that blasting be avoided during project construction if at all possible. If blasting is necessary, the following mitigation measures should be considered:

- Blasting should be conducted in consultation with area residents and businesses and scheduled for the least disturbing time periods.
- Safe limits for ground vibration and air-blast overpressure should be established and included in the contract specifications.
- Mitigation measures, such as minimizing the charge per delay and using weighted covers and blasting mats, should be implemented if practical and if needed to control blasting overpressure and ground vibration.
- Vibration and air-blast monitoring should be performed during all blasting operations to document compliance with the established limits.
- Conditions surveys should be performed at all structures within 500 feet of blasting sites to provide documentation for evaluation of potential damage claims.
- Blasting should be designed and performed by contractors that are certified by the State of Texas.

7.3.2 TBM Mitigation

There are no feasible and practical methods to mitigate the vibration produced by TBM mining. However, TBM mining activities are temporary and any detectable ground-borne vibration or ground-borne noise will occur for a limited number of days depending on the advance rate of the tunneling.

7.3.3 Muck Train Mitigation

Ground-borne vibration and ground-borne noise generated by material supply and muck trains could last for the duration of the tunneling. A primary cause for the high vibration of these trains is the track joint gap size, however other factors contribute such as poor quality rail, mismatched rail profiles, and rigid attachments to the tunnel invert. Potential mitigation options are:

- **Conveyor Belt System:** Utilize a conveyor belt system to remove spoils and muck. Operation of a conveyor belt system is unlikely to cause vibration or ground-borne noise concerns and will reduce the number of material supply train operations.
- **Rail isolation:** Ground-borne noise reduction should be provided by supporting the rails on cross-ties and with an elastomer isolator installed between the floor of the tunnel and the rails and ties.
- High-Quality Rail: Using good quality rail with careful installation, not bent or warped, and free from pits will reduce vibrations.
- **Minimize rail joint gap size or use filler weld at joints:** Typically, material supply and muck train rail is constructed without much regard to the rail joint gap size. As the wheel traverses the gap, a “wheel strike” occurs potentially causing a large vibration event. The joint gap should therefore be minimized, and the use of filler weld should be used if the filler weld is ground to smooth the transition.
- **Train speed control:** Operating the train at a reduced speed will reduce vibration. It has been shown that reducing the train speed by half, reduced the vibration by 3-7 dB depending on the frequency. However, reducing the train speed over long distances may affect completion schedules.
- **Use rubber tire vehicles:** This option removes a rail-based system entirely, as all supplies and/or spoils are conveyed by a vehicle with rubber tires. The use of such a vehicle has the potential to remove all ground-borne noise issues as well as vibration issues except at all but the lowest frequencies (usually below 5 Hz where a tire resonance may occur).
- **Maintenance:** Regardless of the mitigation measures used, over time rail degrades, gaps open, and train speed limits are violated. The construction management team will need to proactively check the condition of the imposed measures and quickly respond to make corrective actions if needed.

8 References

FTA (Federal Transit Administration)

2018 Transit Noise and Vibration Impact Assessment Manual (FTA Report No. 0123).

DART (Dallas Area Rapid Transit)

2017 Environmental Impact Assessment & Mitigation Guidelines for Transit Projects.

HMMH (Harris Miller Miller & Hanson Inc.)

2006 Vehicle Noise and Vibration Level Comparison.

ATS Consulting

2008 Vibration Measurements and Predictions for Central Corridor LRT Project.

FHWA (Federal Highway Administration)

2006 Construction Noise Handbook.

HMMH (Harris Miller Miller & Hanson Inc.)

1993 Vibration from Metro Rail Tunneling Operations, HMMH Report No. 292330 (February 18, 1993).

Appendix A. Measurement Site Photographs

Noise Measurement Site Photographs

Figure A-1: Noise Measurement Site LT-A – Arpeggio Victory Park Apartments

Figure A-2: Noise Measurement Site LT-B – The Vista Dallas

Figure A-3: Noise Measurement Site LT-C – Northend Apartments Dallas

Figure A-4: Noise Measurement Site LT-D – Live Oak Lofts

Figure A-5: Noise Measurement Site LT-E – Elan City Lights Apartments

Figure A-6: Noise Measurement Site ST-A – N Griffin Street and Hord Street

Figure A-7: Noise Measurement Site ST-B – Swiss Avenue and Hawkins Street

Figure A-8: Noise Measurement Site ST-C – 2121 Main Street (Rear)

Vibration Measurement Site Photographs

Figure A-9: Vibration Measurement Site VP-1 – Victory Avenue and High Market Street

Figure A-10: Vibration Measurement Site BH-1 – Commerce Street and Browder Street

Appendix B. Noise Measurement Data

Figure B-1: Long-Term Noise Measurement Data – Site LT-A

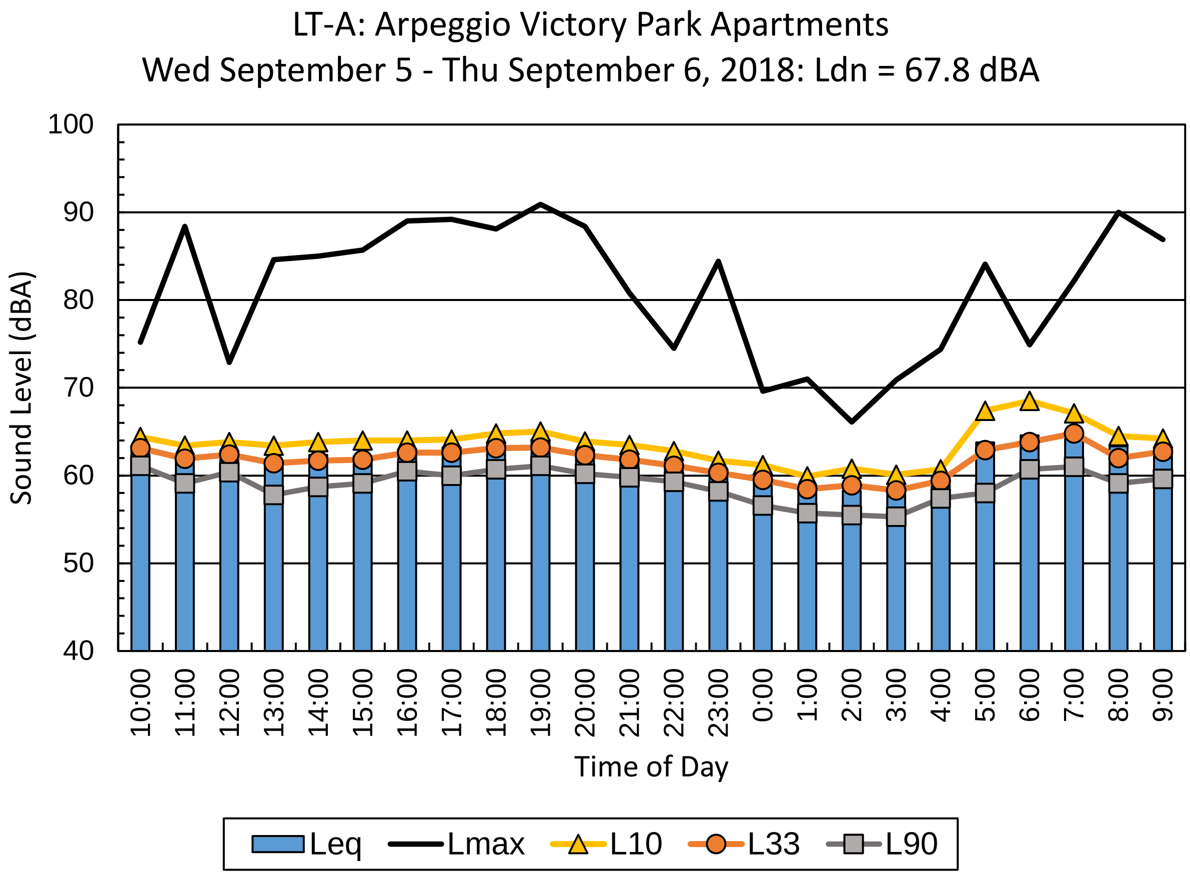


Figure B-2: Long-Term Noise Measurement Data – Site LT-B

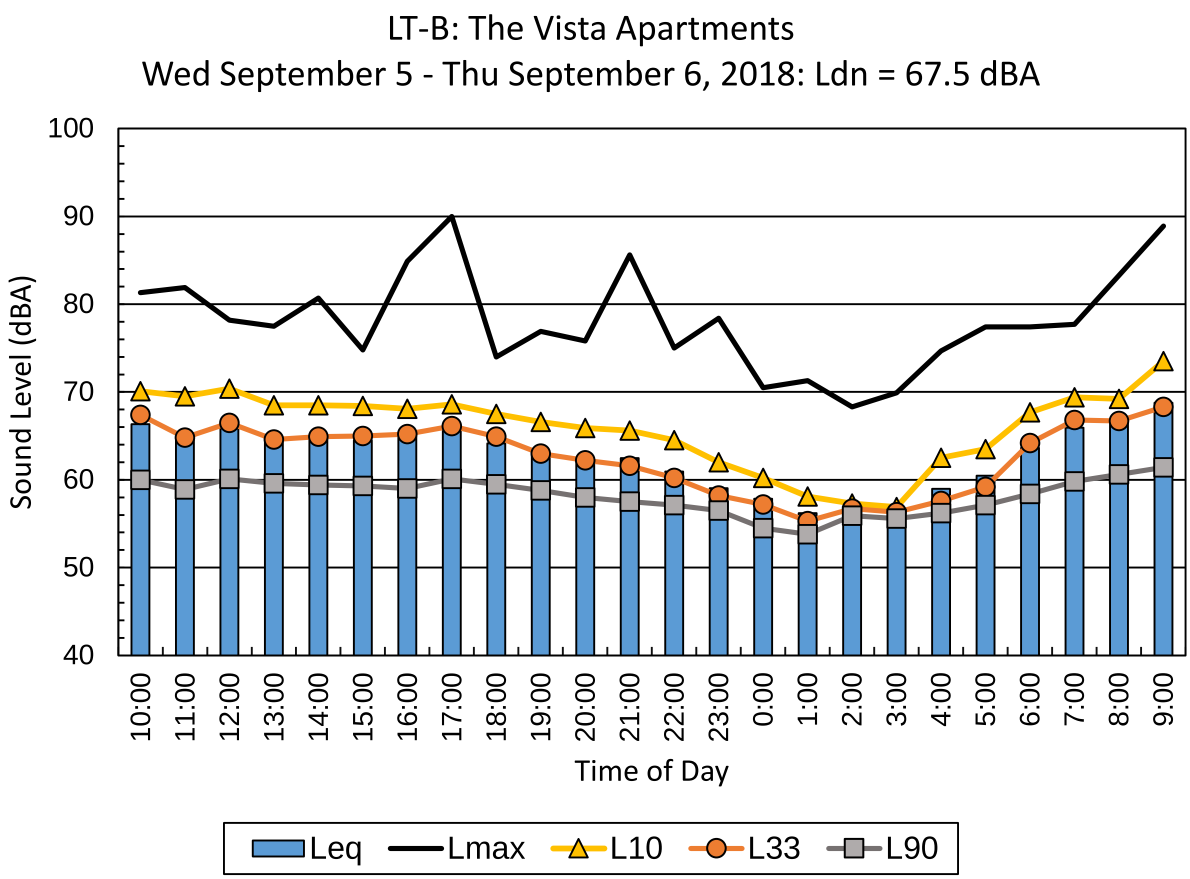


Figure B-3: Long-Term Noise Measurement Data – Site LT-C

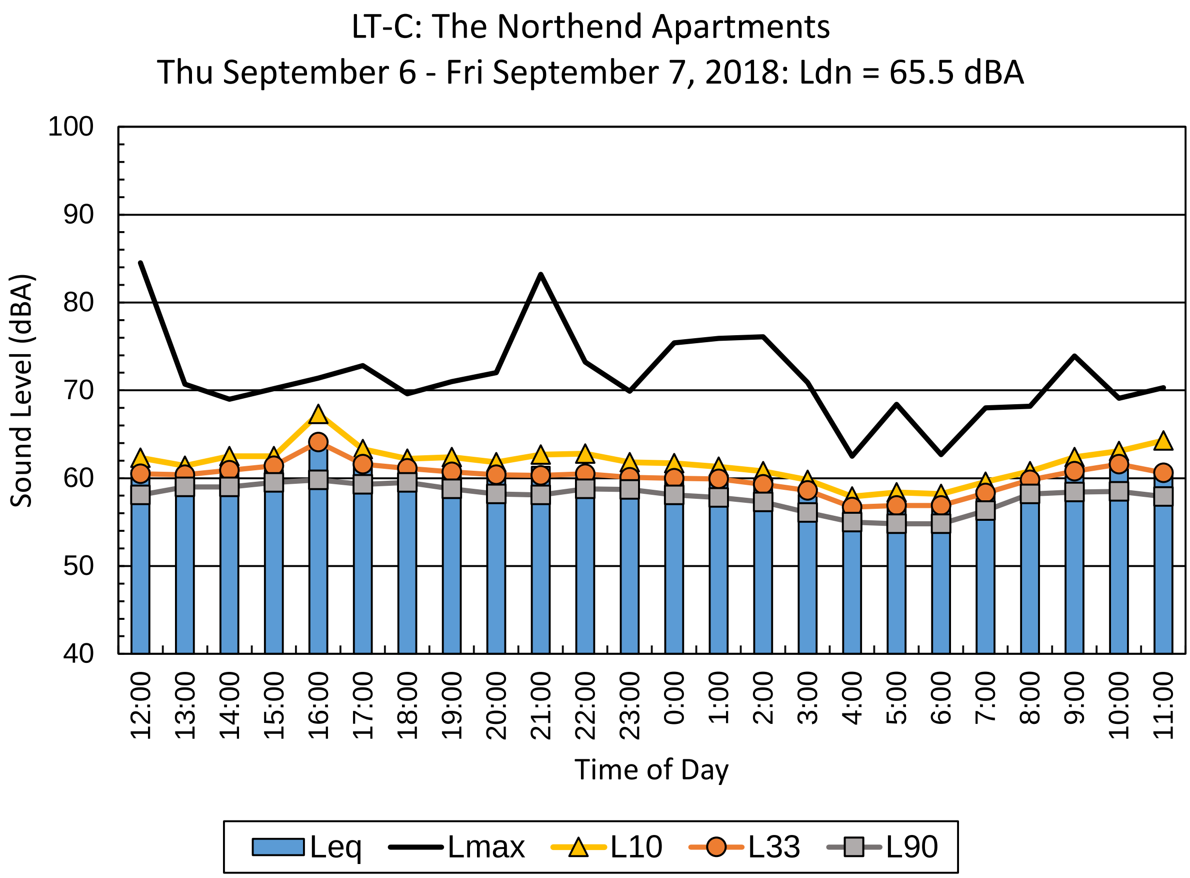

LT-C: The Northend Apartments
Thu September 6 - Fri September 7, 2018: Ldn = 65.5 dBA
Sound Level (dBA)
100
90
80
70
60
50
40
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
Time of Day
Leq
Lmax
L10
L33
L90

Figure B-4: Long-Term Noise Measurement Data – Site LT-D

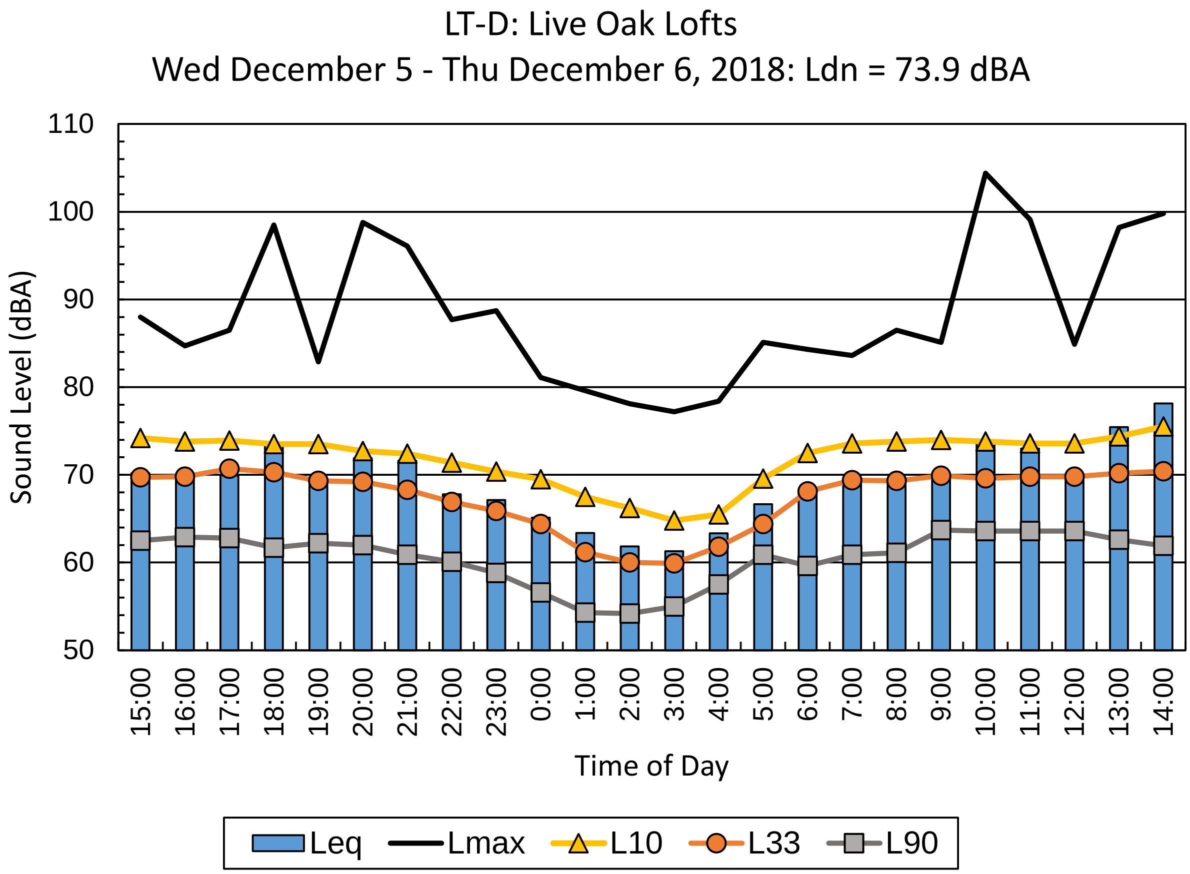
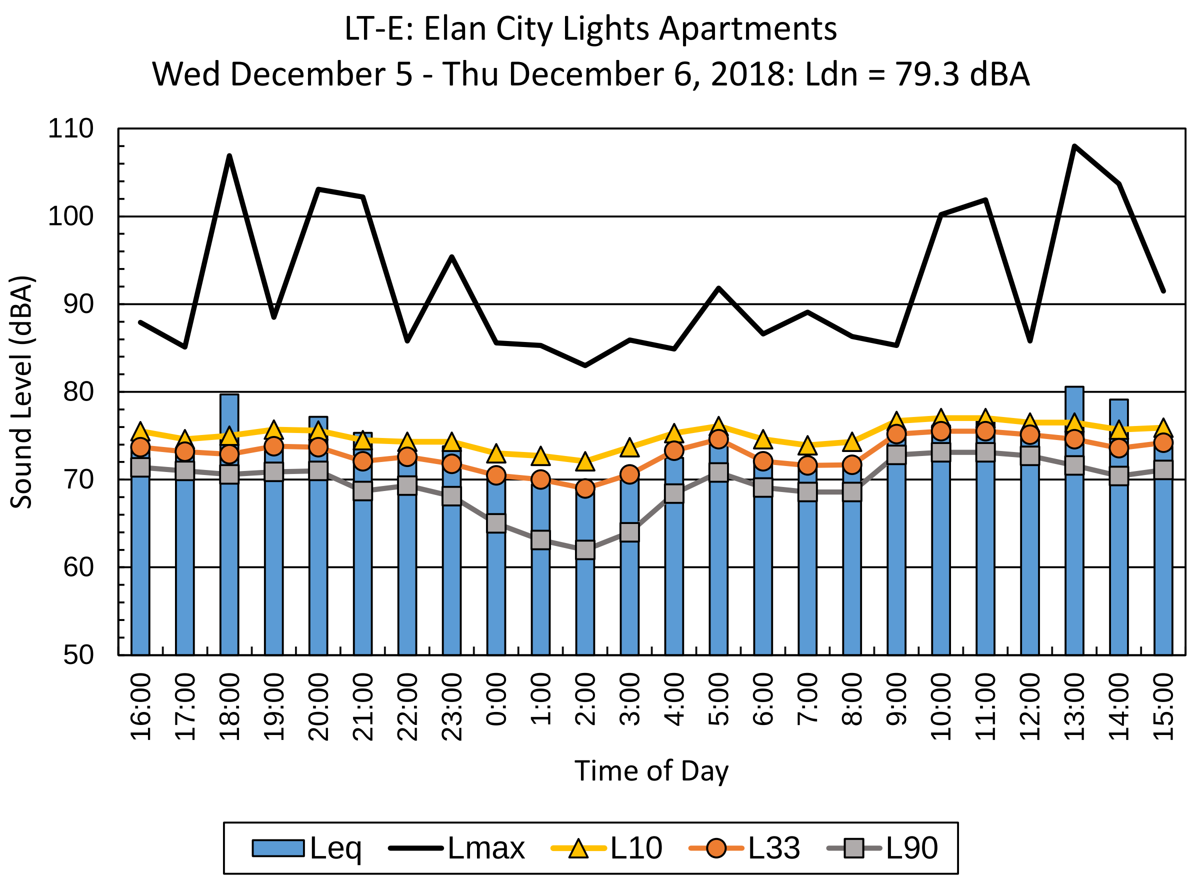


Figure B-5: Long-Term Noise Measurement Data – Site LT-E



Appendix C. Vibration Measurement Data

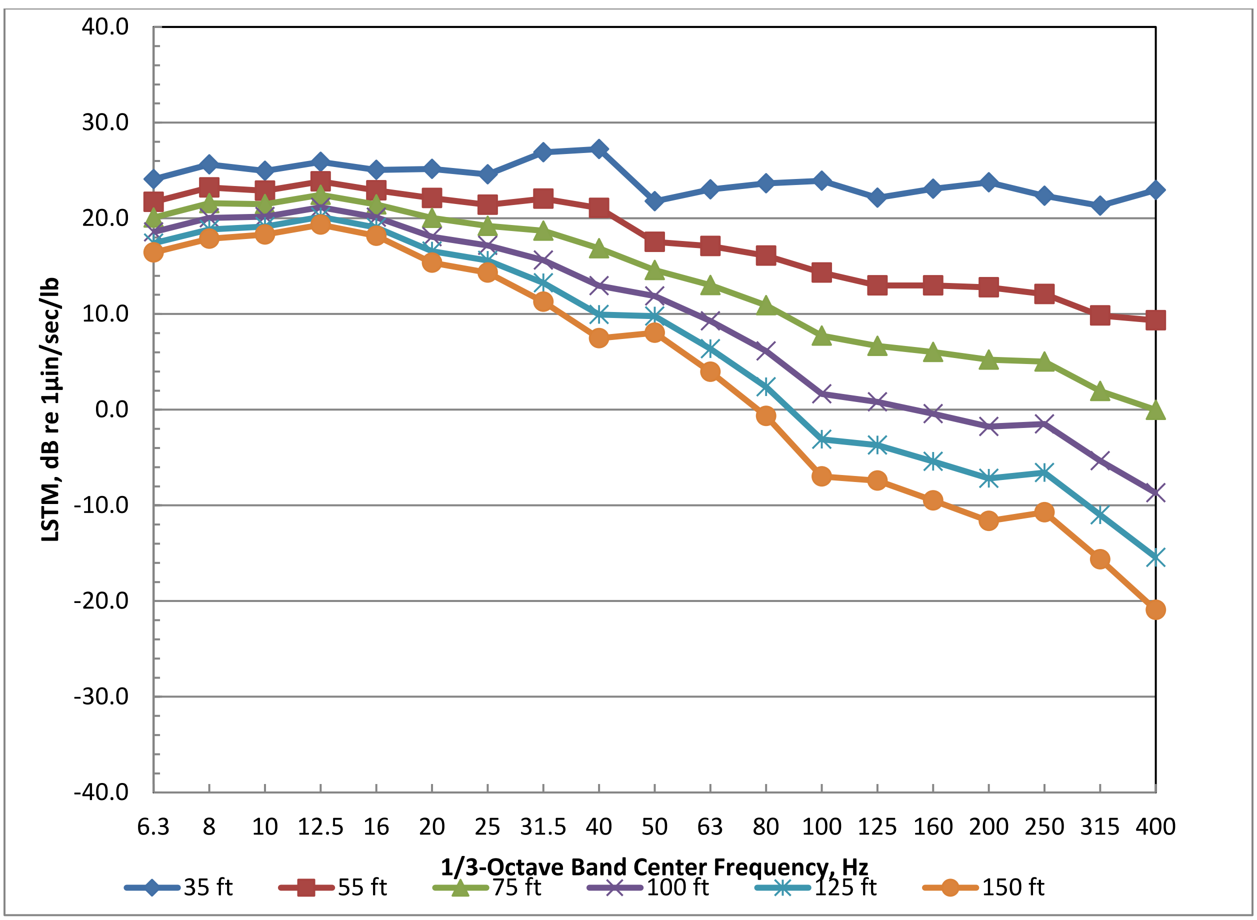
Site VP-1

1/3-Octave Band Transfer Mobility Coefficients – Site VP-1

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	42.8	44.6	41.2	41.9	41.8	49.2	49.7	65.0	75.6	55.4	69.5	83.0	99.4	94.4	102.7	110.2
B	-12.1	-12.3	-10.5	-10.4	-10.9	-15.6	-16.3	-24.7	-31.3	-21.8	-30.1	-38.4	-48.9	-46.8	-51.6	-56.0
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$

Line Source Transfer Mobility, Site VP-1



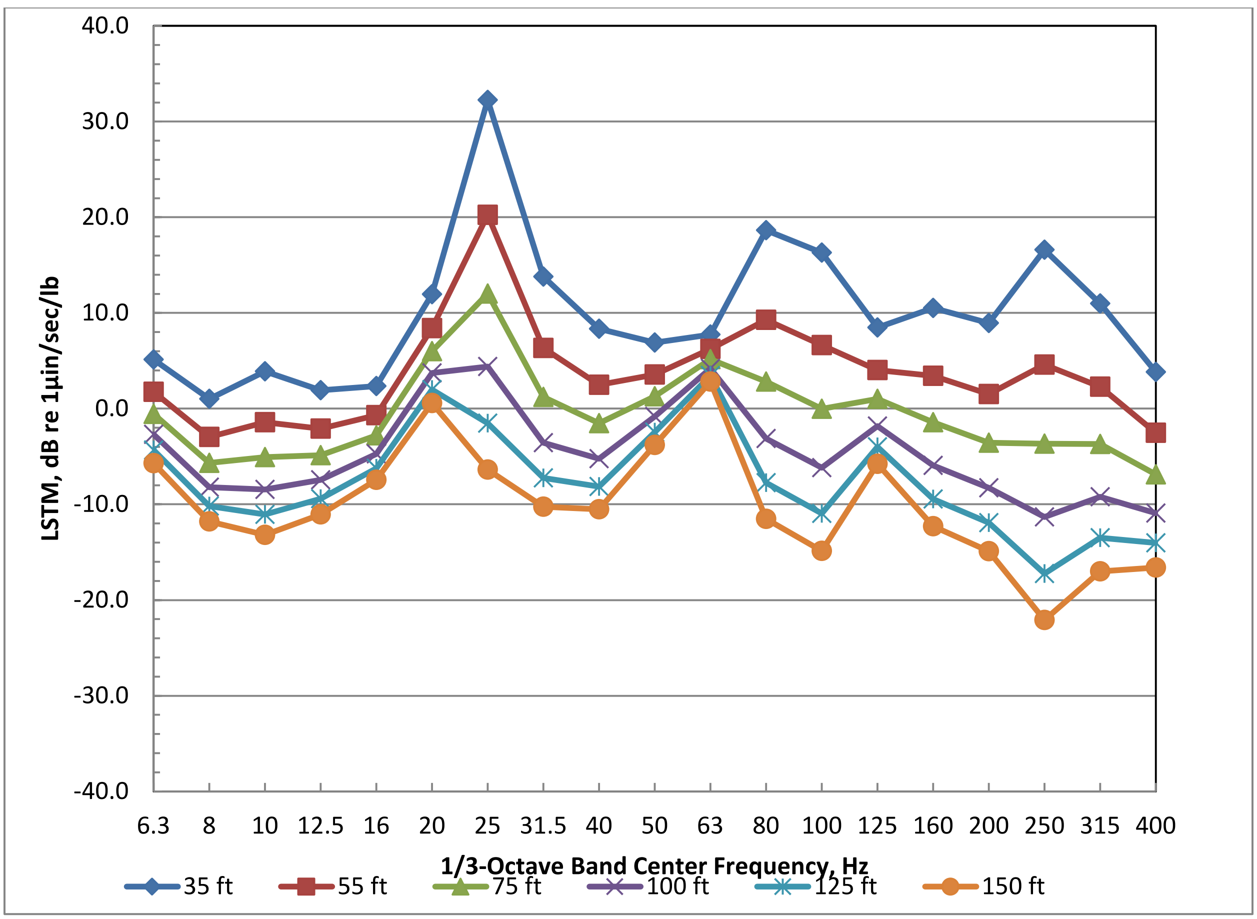
Site BH-1

1/3-Octave Band Transfer Mobility Coefficients – Site BH-1

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	31.5	32.3	45.6	33.6	26.3	39.7	126.5	72.6	54.4	33.1	19.8	92.4	92.4	43.3	66.2	67.2
B	-17.1	-20.3	-27.0	-20.5	-15.5	-18.0	-61.1	-38.1	-29.8	-16.9	-7.8	-47.7	-49.3	-22.5	-36.1	-37.7
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$

Line Source Transfer Mobility, Site BH-1



Technical Memorandum

Date:	Monday, February 10, 2020
Project:	DART GPC VI – D2 Subway LPA
To:	Tom Shelton, HDR, Inc.
From:	David Towers and Scott Edwards, Cross-Spectrum Acoustics Inc.
Subject:	CSA Reference J2016-1020 – Noise and Vibration Assessment – Modified Track Alignment on East End and Addition of Live Oak Station

This technical memorandum summarizes an update to the original *Noise and Vibration Technical Report* for the *DART Dallas CBD Second Light Rail Alignment (D2 Subway), Final Report* dated January 22, 2019. This memorandum summarizes the changes to the noise and vibration impact assessment conducted by Cross-Spectrum Acoustics (CSA) based on modifications to the east end of the alignment, including the relocation of the Deep Ellum Station as the Live Oak Station. The original analysis assumed a west-side running track and removal of the Deep Ellum Station, as well as an option for a junction further north along Good Latimer. As design progressed and stakeholder and public input was considered, DART decided to retain the alignment in the median of Good Latimer, and to relocate the Deep Ellum Station to Live Oak, resulting in a junction to the south of Swiss Avenue.

The results of the investigation are based on a review of current project drawings, updated operational information, data from previous work conducted during the alignment location and engineering efforts, and noise and vibration measurements carried out during the fall and winter of 2018. This memorandum includes a description of the updated D2 project operating plan, and updated results of the noise and vibration impact assessment in accordance with Federal Transit Administration (FTA) methodology. For further details on the D2 project and descriptions of the FTA noise and vibration impact assessment methodology, please refer to the *Noise and Vibration Technical Report* for the *DART Dallas CBD Second Light Rail Alignment (D2 Subway), Final Report* dated January 22, 2019.

Track Alignment Modifications and Live Oak Station

The track modifications are on the east end of the D2 project from the tunnel portal area to the tie-in with the existing DART LRT tracks along Good Latimer Expressway. The revised at-grade alignment runs south of Swiss Avenue and then connects to slightly shifted DART LRT tracks in the median of Good Latimer Expressway. To the north of the tie-in, there is the addition of Live Oak Station with a center platform. Live Oak Station is located approximately at Florence Street and the platform is in front of the Live Oak Lofts, Latino Cultural Center, and St. James A.M.E. Temple.

Figure 1 shows the previous east end track alignment analyzed in the original report. **Figure 2** shows the modified track alignment, as well as the Live Oak Station. As shown, the current design includes a wye in the track as the D2 corridor ties in with the existing DART LRT line along Good Latimer Expressway. With the addition of the Live Oak Station, the crossovers associated with the wye shifted to the southeast, away from nearby noise and vibration sensitive receivers at Live Oak Lofts, Latino Cultural Center, and St. James A.M.E. Temple.

Figure 1 – Previous East End Track Alignment – North of Swiss/West-side Running/No Station

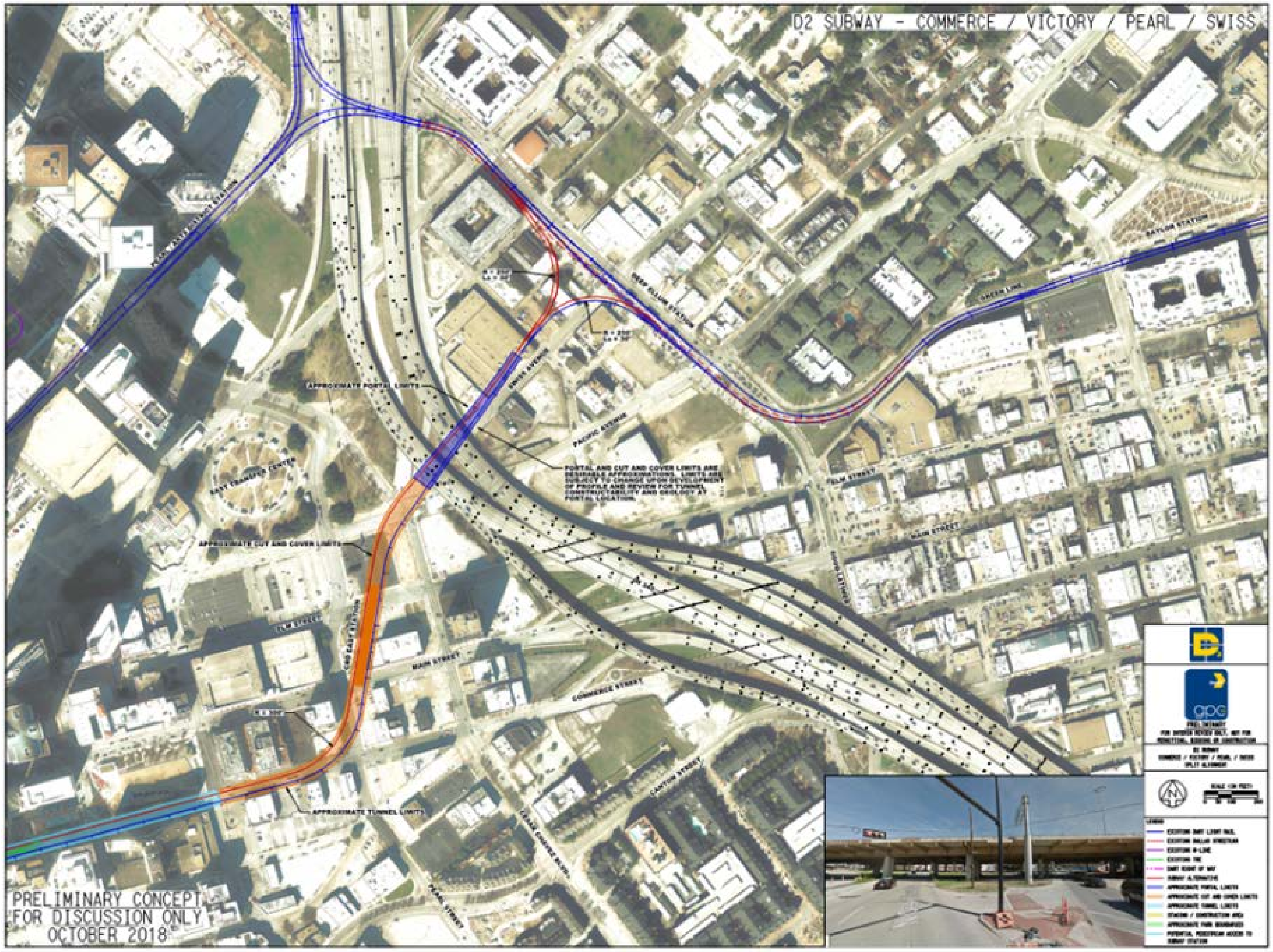
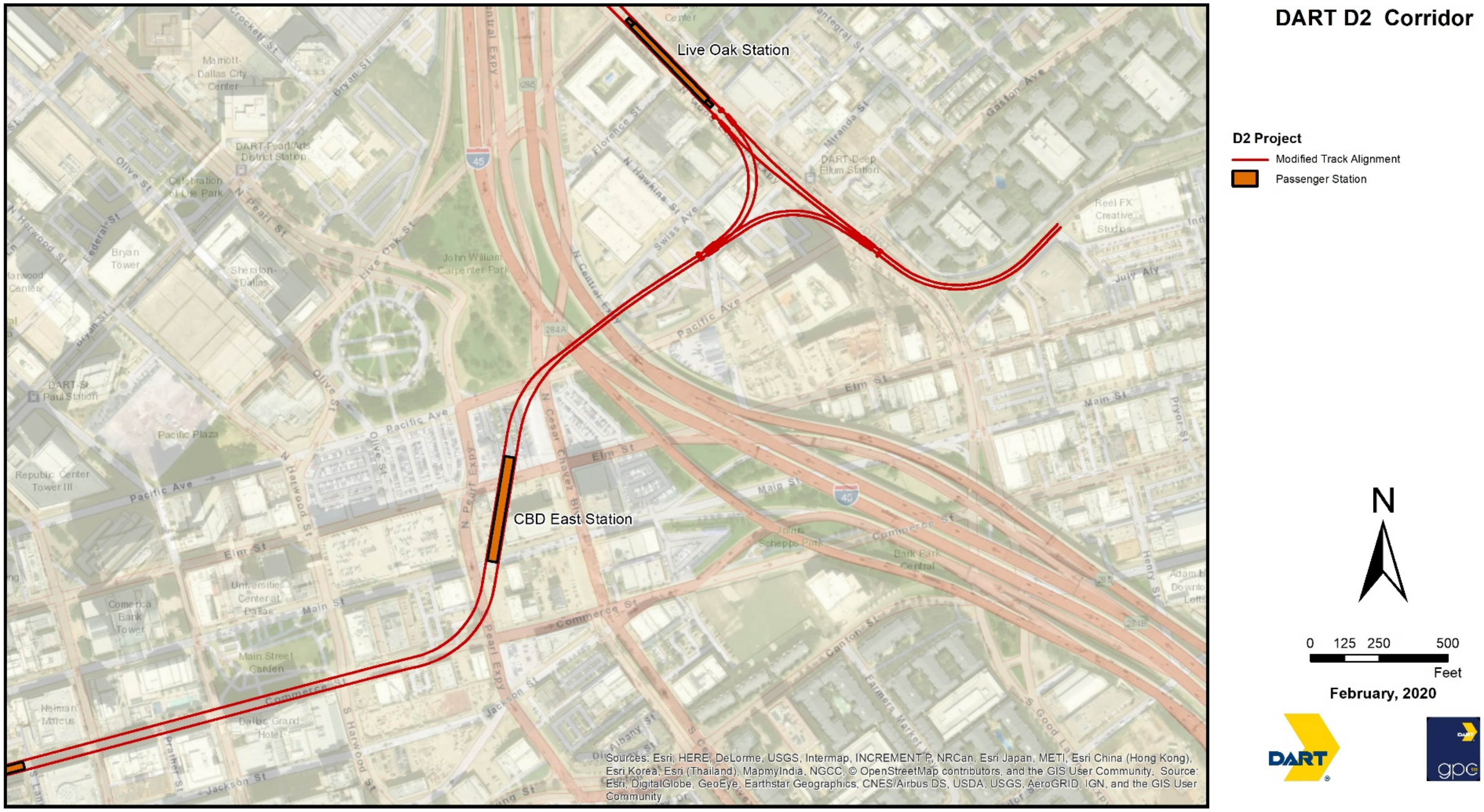


Figure 2 – Modified D2 Subway Alignment – South of Swiss/Median-Running/Live Oak Station



Updated Operating Plan

Connetics Transportation Group provided an Operating Plan for the D2 project dated October 7, 2019. The operating plan includes updates to previously assumed operational speed information in the January 2019 Noise and Vibration Technical Report.

LRT speeds of 15mph were previously assumed everywhere for the noise and vibration impact assessment. The updated operating plan lists an average speed of 12mph for D2 Orange line trains traveling between CBD East Station and Live Oak Station, and an average speed of 25mph for D2 Orange line trains traveling between Live Oak Station and Cityplace/Uptown Station. D2 Green line trains traveling between CBD East Station and Baylor UMC Station are listed as traveling an average speed of 16mph.

These speeds were updated in the noise and vibration impact assessments. All other operational assumptions are the same as in the January 2019 Noise and Vibration Technical Report, as follows:

- Based on measurement data for a prototype DART low-floor SLRV, the predictions assume that a single 124-foot long vehicle operating at 50 mph on at-grade ballast and tie track with continuous welded rail (CWR) generates a Sound Exposure Level (SEL) of 82 dBA at a distance of 50 feet from the track centerline. This value, which corresponds to a reference SEL value of 76 dBA at a speed of 25 mph, is consistent with the FTA reference SEL values for rail cars and streetcars.
- Based on FTA guidance, an adjustment of +3 dBA is applied to the noise computations in areas where the trains will be operating at grade on embedded or direct fixation track to account for the noise increase relative to operation on ballast and tie track.
- It is assumed that all trains will consist of three vehicles, although actual operations may have shorter trains depending on time of day.
- Based on the current DART Orange Line and Green Line weekday schedules, it is assumed that there will be 102 trains operating during the daytime hours (7 am to 10 pm) and 30 trains operating during the nighttime hours (10 pm to 7 am) in each direction. This schedule corresponds to a total of 264 trains passing by a given location during a 24-hour weekday period. Peak transit hour headways are assumed to be 15 minutes on each of the two lines, with eight trains per hour passing by in each direction.
- It is assumed that the above train volumes are reduced by one half beyond the Good Latimer junction where Green Line trains turn south toward Baylor University Medical Center Station on the Southeast Corridor and where Orange Line trains turn north toward the Live Oak Lofts to the North Central Corridor.
- Based on DART audible warning signal equipment and policy, train whistles are assumed to generate a sound level of 78 dBA at 50 feet from the track for a five-second period as trains approach gated grade crossings. It is assumed that gated crossings will be at Broome Street, McKinney Avenue, Hawkins Street, Swiss Avenue, and Pacific Avenue and that traffic signals will be used at all other crossings without audible warning signals.

- Stationary warning bells, generating a sound level of 73 dBA at 50 feet, would be sounded at gated grade crossings before and after each train for a total duration of 30 seconds. It is assumed that gated crossings will be at Broome Street, McKinney Avenue, Hawkins Street, Swiss Avenue (southbound movements from Good Latimer only), and Pacific Avenue (southbound movements from Good Latimer only).
- Based on FTA guidance, wheel impacts at crossovers and turnouts are assumed to cause localized noise increases of 5 dBA within a distance of 300 feet.
- Vibration source level data for the DART vehicle operating at grade on ballast and tie track with continuous welded rail (CWR) were obtained from measurements conducted on a prototype DART low-floor SLRV.
- The source level data were adjusted for speed and for embedded track conditions (where applicable) based on data from vibration measurements for the Central Corridor LRT Project (METRO Green Line) in Minneapolis-St. Paul, MN.
- Vibration propagation tests were conducted at two sites along the D2 alignment as described in the January 2019 Noise and Vibration Technical Report. These tests measured the response of the ground to an input force. The results of these tests were combined with vibration source level data for the DART vehicle to project vibration levels from trains operating along the project corridor.
- Based on FTA guidance, wheel impacts at track crossovers and turnouts are assumed to cause localized vibration increases of 10 VdB within a distance of 100 feet, and increases of 5 VdB at distances between 100 feet and 200 feet.
- The ground-to-building coupling loss (i.e. vibration reduction) is assumed to be 7 VdB for 1-2 story buildings and 10 VdB for taller buildings.
- A floor-to-floor attenuation (i.e. vibration reduction) of 2 VdB/floor is assumed.

Updated Noise Impact Assessment Results

A detailed noise impact assessment was carried out based on FTA noise impact assessment methodology described in the January 2019 Noise and Vibration Technical Report. The assessment was revised based on the latest D2 project design including the track modifications, addition of Live Oak Station, and updated operating plan. Additional noise from passenger station operations was modeled for the noise sensitive receptors in the vicinity of the newly added Live Oak Station. The revised noise assessment results are presented below.

Comparisons of the existing and future noise levels are presented in **Table 1**, including results for FTA Category 2 (residential) receptors with both daytime and nighttime sensitivity to noise, and for FTA Category 3 (institutional) receptors with primarily daytime and evening use. In addition to the distances to the track and proposed train speeds, **Table 1** includes the existing noise levels, the projected noise levels from light rail operations, the predicted total noise levels and the projected noise increases due to the D2 Project. Based on a comparison of the predicted project noise levels with the impact criteria, the table also includes an inventory of the number of moderate and severe noise impacts for each noise-sensitive receiver.

The results in **Table 1** identify moderate noise impacts at an estimated total of 176 residences, with projected noise increases of 1-2 decibels; no severe impacts are projected. The locations of the potential noise impacts are at three residential buildings as shown in **Figure 3**, including the W Dallas Residences, the Vista Apartments, and the Northend Apartments. This is consistent with the January 2019 report as no project changes occurred in this section.

The revised noise impact assessment resulted in a change of impact at the Live Oak Lofts from moderate impact to no impact. The change was caused by the shifting of tracks away from the multi-family residence and the increased distance to the turnout at the tie-in with the existing DART LRT tracks.

TABLE 1. SUMMARY OF NOISE IMPACTS WITHOUT MITIGATION

Noise-Sensitive Receiver Description	FTA Land Use Category	Side of Track[1]	Distance from Near Track (feet)	Train Speed (mph)	Existing Noise Level[2]	Project Noise Level[2]			Total Noise Level[2]	Noise Level Increase[2]	Number of Residential Impacts	
						Predicted[3]	Impact Criteria					
							Moderate	Severe			Moderate	Severe
Arpeggio Victory Park Apartments	2	NB	23	15	68	62	63	68	69	1.1	0	0
W Dallas Residences	2	NB	34	15	68	64	62	68	69	1.6	96	0
The Vista Apartments	2	SB	43	15	68	63	62	68	69	1.3	48	0
Northend Apartments	2	NB	35	15	66	64	61	66	68	2.3	32	0
Perot Museum of Nature and Science	3	NB	254	15	61	54	63	69	62	0.8	0	0
SkyHouse Dallas Apartments	2	SB	251	15	66	57	61	66	66	0.6	0	0
Dallas World Aquarium	3	SB	81	15	62	58	64	69	63	1.3	0	0
IPS Psychotherapist Office	3	SB	59	15	63	58	64	70	64	1.2	0	0
Elan City Lights Apartments	2	NE	66	25	79	57	65	75	79	0.0	0	0
Latino Cultural Center	3	NE	81	12	69	57	69	74	69	0.3	0	0
Live Oak Lofts	2	SW	48	12	74	61	65	72	74	0.2	0	0
St. James A.M.E. Temple	3	NE	51	12	69	64	69	74	70	1.2	0	0
Epic Deep Ellum	2	SB	85	16	74	62	65	72	74	0.3	0	0
Marquis on Gaston Apartments	2	NB	61	16	74	64	65	72	74	0.4	0	0
TOTAL NUMBER OF NOISE IMPACTS:											176	0

TABLE 1. SUMMARY OF NOISE IMPACTS WITHOUT MITIGATION

Noise-Sensitive Receiver Description	FTA Land Use Category	Side of Track[1]	Distance from Near Track (feet)	Train Speed (mph)	Existing Noise Level[2]	Project Noise Level[2]			Total Noise Level[2]	Noise Level Increase[2]	Number of Residential Impacts	
							Impact Criteria					
						Predicted[3]	Moderate	Severe			Moderate	Severe

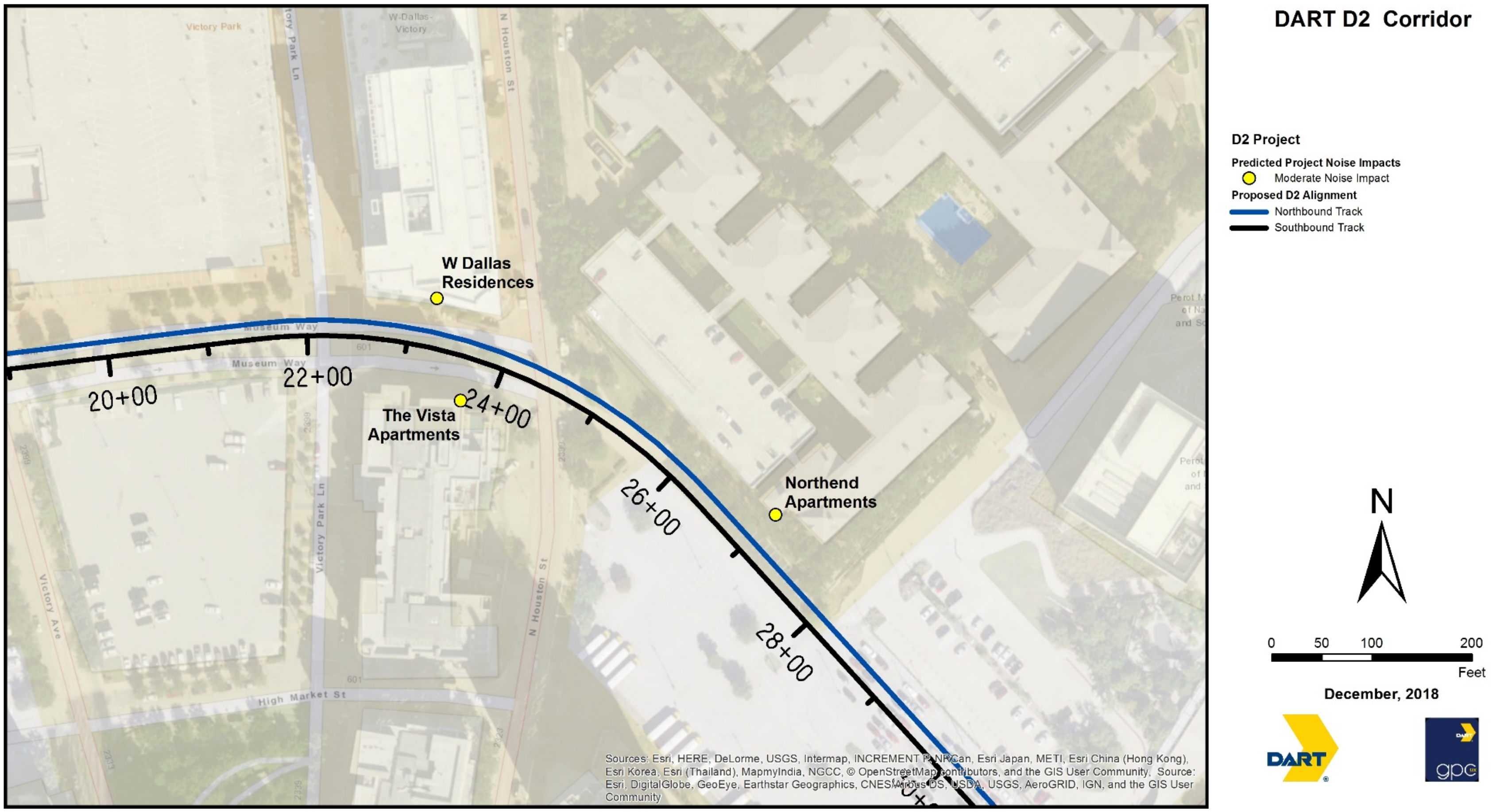
Source: Cross-Spectrum Acoustics, 2020

[1] Relative to track for trains in Northbound (NB) direction heading towards Victory Station or for trains in Southbound (SB) direction heading away from Victory Station; Northeast (NE) or Southwest (SW) side of track (relative to N Good Latimer Expressway).

[2] Noise levels are measured in dBA (rounded to the nearest decibel) and are based on Ldn for FTA Land Use Category 2 receivers and on Leq for FTA Land Use Category 3 receivers. For better resolution, noise level increases are shown to the nearest 0.1 decibel.

[3] Predicted levels include whistle, bell and passenger station noise, where applicable (rounded to the nearest decibel).

FIGURE 3. NOISE IMPACT LOCATIONS WITHOUT MITIGATION (VICTORY DEVELOPMENT)



Source: Cross-Spectrum Acoustics, 2019

Updated Vibration Impact Assessment Results

A detailed vibration impact assessment was carried out based on FTA noise impact assessment methodology described in the January 2019 Noise and Vibration Technical Report. The assessment was revised based on the latest D2 project design and operating plan. The revised vibration assessment results are presented below.

Table 2 provides an assessment of potential ground-borne vibration and noise impact at sensitive receptors from light rail operations. The table includes the distance to the near track, the train speed, the impact criteria, and the projected future ground-borne vibration and noise levels. The results in **Table 2** indicate that no ground-borne vibration or ground-borne noise impacts are projected.

The revised vibration impact assessment resulted in a change of impact at the Live Oak Lofts from 36 ground-borne vibration impacts and 54 ground-borne noise impacts to no impact. The change was caused by the shifting of tracks away from the multi-family residence and the increased distance to the turnout at the tie-in with the existing DART LRT tracks.

TABLE 2. SUMMARY OF GROUND-BORNE VIBRATION AND NOISE IMPACTS WITHOUT MITIGATION

Noise-Sensitive Receiver Description	Side of Track[1]	Distance from Near Track (feet)	Train Speed (mph)	Ground-Borne Vibration[3]			Ground-Borne Noise[3]		
				Predicted GBV Level (VdB)[2]	GBV Impact Criterion (VdB)[2]	Number of GBV Impacts	Predicted GBN Level (dBA)[5]	GBN Impact Criterion (dBA)[5]	Number of GBN Impacts
Arpeggio Victory Park Apartments	NB	23	15	51	72	0	31	35	0
W Dallas Residences	NB	34	15	47	72	0	25	35	0
The Vista Apartments	SB	43	15	51	72	0	28	35	0
Northend Apartments	NB	35	15	56	72	0	35	35	0
Perot Museum of Nature and Science	NB	254	15	32	78	0	1	40	0
SkyHouse Dallas Apartments	SB	251	15	32	72	0	1	35	0
Dallas World Aquarium	SB	83	15	44	78	0	18	40	0
Ross Apartments	SB	81	15	33	72	0	11	35	0
KDFW FOX4 TV Studio	NB	108	15	38[4]	65[4]	0	11	25	0
Crowne Plaza Dallas Downtown	SB	69	15	34	72	0	11	35	0
Homewood Suites by Hilton Dallas	NB	113	15	29	72	0	5	35	0
Earle Cabell Federal Building and Courthouse	SB	82	15	33	78	0	11	40	0
Metropolitan Condos	NB	72	15	34	72	0	11	35	0
Manor House Apartments	SB	71	15	34	72	0	11	35	0

TABLE 2. SUMMARY OF GROUND-BORNE VIBRATION AND NOISE IMPACTS WITHOUT MITIGATION

Noise-Sensitive Receiver Description	Side of Track[1]	Distance from Near Track (feet)	Train Speed (mph)	Ground-Borne Vibration[3]			Ground-Borne Noise[3]		
				Predicted GBV Level (VdB)[2]	GBV Impact Criterion (VdB)[2]	Number of GBV Impacts	Predicted GBN Level (dBA)[5]	GBN Impact Criterion (dBA)[5]	Number of GBN Impacts
The Adolphus Hotel	NB	71	15	34	72	0	11	35	0
The Magnolia Hotel	NB	69	15	34	72	0	11	35	0
The Joule Hotel	NB	138	15	28	72	0	3	35	0
Dallas Power and Light Flats	SB	78	15	32	72	0	10	35	0
The Merc Apartments	NB	68	15	45	72	0	22	35	0
Hampton Inn Dallas Downtown	SB	68	15	40	72	0	17	35	0
The Element Apartments	NB	153	15	33	72	0	7	35	0
The Continental Apartments	SB	72	15	43	72	0	21	35	0
The Statler Residences	SB	71	15	34	72	0	11	35	0
UNT Dallas College of Law	NB	64	15	38	78	0	15	40	0
Dallas Municipal Court	NB	58	15	40	78	0	16	40	0
IPS Psychotherapist Office	SB	65	15	38	78	0	15	40	0
Elan City Lights Apartments	NE	66	25	47	72	0	22	35	0
Latino Cultural Center	NE	81	12	45	78	0	19	40	0
Live Oak Lofts	SW	48	12	52	72	0	28	35	0

TABLE 2. SUMMARY OF GROUND-BORNE VIBRATION AND NOISE IMPACTS WITHOUT MITIGATION

Noise-Sensitive Receiver Description	Side of Track[1]	Distance from Near Track (feet)	Train Speed (mph)	Ground-Borne Vibration[3]			Ground-Borne Noise[3]		
				Predicted GBV Level (VdB)[2]	GBV Impact Criterion (VdB)[2]	Number of GBV Impacts	Predicted GBN Level (dBA)[5]	GBN Impact Criterion (dBA)[5]	Number of GBN Impacts
St. James A.M.E. Temple	NE	51	12	51	78	0	27	40	0
Epic Deep Ellum	SB	85	16	49	72	0	23	35	0
Marquis on Gaston Apartments	NB	61	16	48	72	0	24	35	0
TOTAL NUMBER OF IMPACTS					**GBV:**	**0**		**GBN:**	**0**

Source: Cross-Spectrum Acoustics, 2020

[1] Relative to track for trains in Northbound (NB) direction heading towards Victory Station or for trains in Southbound (SB) direction heading away from Victory Station; Northeast (NE) or Southwest (SW) side of track (relative to N Good Latimer Expressway).

[2] Maximum one-third octave frequency band ground-borne vibration velocity level, measured in VdB referenced to 1 µin/sec (rounded to the nearest decibel).

[3] The predicted vibration and noise levels assume a ground-to-building vibration coupling loss of 7 VdB for 1-2 story buildings and 10 VdB for taller buildings.

[4] This is a FTA Land Use Category 1 receiver and the level represents the overall ground-borne vibration velocity level, measured in VdB referenced to 1 µin/sec (rounded to the nearest decibel). The ground-borne vibration impact criterion for FTA Land Use Category 1 receivers is based on the overall vibration level and is specific to the type of building. The ground-borne vibration impact criterion for TV studios is 65 VdB.

[5] Maximum overall ground-borne noise level, measured in dBA referenced to 20µPa.