LYNX Blue Line Extension

(Northeast Corridor)

Light Rail Project

Contract #: 08-477

WBS #: 6.12

Detailed
Noise and Vibration Technical Report

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Project #: 2513745

August 23, 2011

Rev. 02

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1.0 INTRODUCTION AND SUMMARY

This report presents the findings of a detailed noise and vibration impact assessment and mitigation analysis conducted for the proposed LYNX Blue Line Extension Northeast Corridor Light Rail Project (LYNX BLE). This analysis has been conducted as a follow-up to the analysis conducted for the Draft Environmental Impact Statement (EIS). The project would extend light rail transit service from the existing Blue Line terminus at 7th Street in Center City Charlotte approximately 9.5 miles to the University of North Carolina at Charlotte (UNC Charlotte) campus. The assessment was carried out in conformance with the procedures and criteria prescribed in the U.S. Federal Transit Administration (FTA) guidance manual “Transit Noise and Vibration Impact Assessment” (Final Report No. FTA-VA-90-1003-06, May 2006).

A summary of the study results is presented below. Section 2 provides a discussion of environmental noise and vibration basics, and Section 3 describes the criteria used to assess noise and vibration impact. Section 4 describes existing noise and vibration conditions and Section 5 presents noise and vibration measurement results. Section 6 describes the noise and vibration projections and impact assessment of future noise and vibration conditions, and potential mitigation measures are outlined in Section 7.

Appendix A includes measurement site photographs. Vibration propagation, freight and Amtrak train vibration pass-by data and ambient vibration measurement results are provided in Appendices B, C and D, respectively. A figure depicting the noise and vibration measurement locations is provided in Appendix E and figures showing specific noise and vibration impact and mitigation locations are included in Appendix F. Appendix G includes noise projections at all receptors and Appendix H includes vibration projections at all receptors. Appendix I includes vibration projections for potential structural damage from construction activities and Appendix J includes vibration projections for potential construction vibration impact to sensitive equipment.

1.1 Noise Impact Assessment for Train Operations

The proposed LYNX BLE would introduce a new noise source into the environment which has the potential to cause impact to sensitive receptors. Prior to mitigation, potential severe noise impacts would occur at three sensitive receptors including a single-family residence at 328 Parkwood Avenue (Appendix F, Figure 3), the UNC Charlotte Laurel Residence Hall and UNC Charlotte Spruce Residence Hall (Appendix F, Figure 6) and moderate noise impacts would occur at seven sensitive receptors including two multi-family buildings at 311 East 12th Street (Appendix F, Figure 2) single-family residences at 402 East 19th Street (Appendix F, Figure 3), 352, 358 and 364 Leafmore Drive (Appendix F, Figure 4) and the Marriott Residence Inn Hotel at 8503 North Tryon Street/US-29 (Appendix F, Figure 5).

Noise impact at 311 East 12th Street is due primarily to the horn sounding through the gated at-grade crossing at 12th Street. Noise impacts at 328 Parkwood Avenue and 402 East 19th Street near Parkwood Station are due primarily to the potential for wheel squeal on tight-radius curves. Noise impact near Leafmore Drive is due to the close proximity of sensitive receptors to the proposed alignment and the speed of the trains. Noise impact at 8503 North Tryon Street/US-29 is due primarily to the proximity to the proposed crossing bells at Ken Hoffman Drive gated grade-crossing and the horn sounding of the train. Noise impact at UNC Charlotte Spruce and Laurel Residence Halls near UNC Charlotte Station is due primarily to increased noise levels from a double-crossover and the potential for wheel squeal.

1.2 Noise Mitigation for Train Operations

To mitigate the potential moderate noise impact at 311 East 12th Street (Alpha Mill Apartments), a noise barrier approximately 600 feet in length and four feet in height on the east side of the proposed alignment would be reasonable, feasible and effective in reducing impact. Mitigation for these moderate noise impacts is required because existing noise levels are greater than 65 Ldn from noise sources similar to the proposed project, and these moderate impacts should be considered as though they were severe based on FTA guidance. The barrier would be at-grade for approximately 200 feet and then transition to the top of the proposed retaining wall for the elevated guideway which eventually goes over the CSX railroad. The estimated cost for this noise barrier is $72,000 based on $30 per square foot for materials. For the historic building adjacent to the railroad corridor, the noise barrier would reduce noise approximately five decibels and future noise levels would be below the moderate criterion. For the building on the south side of 12th Street, the noise barrier would reduce noise approximately 2-3 decibels, and would not completely mitigate the potential impact. Therefore, this building is a candidate for sound insulation improvements. Sound insulation improvements would be necessary if future interior noise levels with the existing windows would exceed 45 Ldn. During Final Design, the existing outdoor-to-indoor noise reduction of the units will be tested to determine the need for sound insulation improvements. These tests are conducted by playing noise through a speaker outside the building and measuring the levels inside and outside with the windows and doors closed.

To mitigate potential severe noise impact at 328 Parkwood Avenue and moderate noise impact at 402 East 19th Street near Parkwood Station, installing an automated top of rail friction modifier system on curve LRT NB-5/SB-5 at station number 1055+00 would be reasonable, feasible and effective in reducing potential wheel squeal. With mitigation, project noise levels would be four to seven decibels below the moderate noise impact criterion. Automated top of rail friction modifier systems are estimated to cost $15,000 each ($30,000 for both tracks).

To mitigate potential moderate noise impact at Leafmore Drive, a noise barrier approximately 600 feet long (station number 1192+00 to 1198+00) and approximately 10 feet in height would be effective in reducing future noise levels, including noise from existing Amtrak and freight trains by five decibels or more. Mitigation for these moderate noise impacts is required because existing noise levels are greater than 65 Ldn from noise sources similar to the proposed project and these moderate impacts should be considered as though they were severe based on FTA guidance. The estimated cost of this noise barrier is $180,000 based on $30 per square foot for materials.

To mitigate potential moderate noise impact at 8503 North Tryon Street/US-29 (Marriott Residence Inn), sound insulation improvements to approximately 16 units, including first and second floor units, closest to North Tryon Street/US-29 would be effective in mitigating potential noise impact. Noise barriers would not be effective mitigation measures for the units due to the large gap that would be needed for the driveway providing access to North Tryon Street/US-29. Mitigation for these noise impacts must be considered because existing noise levels are greater than 65 Ldn from noise sources similar to the proposed project and these moderate impacts should be considered as though they were severe. Sound insulation improvements would be necessary if future interior noise levels with the existing windows would exceed 45 Ldn. During Final Design, the existing outdoor-to-indoor noise reduction of the units will be tested to determine the need for sound insulation improvements. These tests are conducted by playing noise through a speaker outside the building and measuring the levels inside and outside with the windows and doors closed. Because the hotel already has central heating, ventilation and air-conditioning (HVAC), no improvements to the HVAC system are required. The estimated cost for sound insulation improvements to these 16 units is $400,000 based on a unit cost of $25,000.

Mitigation for potential severe noise impact at UNC Charlotte Spruce Hall and UNC Charlotte Laurel Hall would include an automated top of rail friction modifier system on curve LRT NB-27/SB-39 at station number 3133+00 and the use of specially-engineered hardware for the double-crossover just west of the proposed UNC Charlotte Station. Specially-engineered hardware may include flange-bearing or spring-rail frogs to minimize the gaps in the rail running surface associated with the double-crossover. With mitigation, future noise levels at these receptors would be four decibels below the moderate noise impact criterion. Automated top of rail friction modifier systems are estimated to cost $15,000 each ($30,000 for both tracks). Spring-rail frogs are estimated to cost $8,000 each.

1.3 Vibration Impact Assessment for Train Operations

The proposed LYNX BLE would introduce a new source of vibration into the environment. Prior to mitigation, vibration impact would occur at 332 St. Anne Place (Appendix F, Figure 6) due to the close proximity of this single-family residence to the proposed alignment and the speed of the trains.

Potential vibration impact has been assessed at the Charlotte Research Institute (CRI) located on the UNC Charlotte campus which includes classrooms, labs and vibration-sensitive equipment. Duke Centennial Hall and Grigg Hall are located approximately 500 feet away from the proposed alignment and include equipment with sensitivity to vibration as low as the general vibration criterion (VC)-E criterion. The Bioinformatics building is located approximately 200 feet from the proposed alignment and includes a DNA microarray on the third floor with VC-B sensitivity to vibration. The EPIC building is currently under construction approximately 1000 feet from the proposed alignment and is expected to have vibration-sensitive equipment. The Portal building is being planned for construction approximately 200 feet from the proposed alignment and is also expected to have vibration-sensitive equipment. Potential vibration impact has also been assessed at the Carolinas Medical Center–University (CMC-University) hospital which is approximately 240 feet from the proposed alignment and includes hospital beds and vibration-sensitive equipment.

Without mitigation, vibration impact to sensitive equipment is not anticipated at the UNC Charlotte CRI. Future vertical vibration levels from LYNX BLE operations would be below the VC-E criterion for sensitive equipment on the ground floor of the Bioinformatics building, Grigg Hall, Duke Centennial Hall and EPIC building (under construction) and would not impact vibration-sensitive equipment. Without mitigation, vibration impact is not anticipated at vibration-sensitive equipment or hospital beds at CMC-University. Future vibration levels would be below the VC-D criterion on the ground floor.

1.4 Vibration Mitigation for Train Operations

Approximately 150 feet of track vibration isolation treatment (station number 1202+50 to 1204+00) installed in the LYNX BLE trackform would be effective in mitigating potential vibration impact at 332 St. Anne Place. Treatments such as ballast mats and tire derived aggregate (TDA, otherwise known as shredded tires) can reduce vibration levels from light rail trains by up to 15 VdB. With such mitigation, vibration levels from light rail trains would be below the vibration impact criterion. The estimated cost for vibration isolation such as ballast mats is $54,000 based $180 per track-foot and $18,000 for TDA based on $60 per track-foot for 300 track-feet of treatment.

1.5 Construction Noise and Vibration Impact Assessment

Construction of the proposed project would introduce short-term noise and vibration sources to the environment which may cause impact to sensitive receptors. The primary construction activities include at-grade track, station, parking lot, elevated guideway, retaining wall, bridge, underpass and parking deck construction. Although construction noise and vibration is highly-dependent on the specific construction methods used by the contractor, the following information provides a worst-case analysis of the potential for impact prior to mitigation. Depending on the land use category (i.e. residential, commercial or industrial) and time of day, potential impact from construction noise may occur within 197 feet for at-grade track, station and parking lot construction, within 280 feet for road construction and within 331 feet for construction involving pile driving such as that for elevated guideways retaining walls, bridges, underpasses and parking decks. Sensitive receptors within these distances to potential construction noise impact include 19 residential properties, nine hotels or motels, 12 commercial properties and five industrial properties as shown in Appendix F, Figure 8a and 8b and Table 1.

Table 1
Summary of potential construction noise impact prior to mitigation

Receptor Number	Receptor Location	Land Use Type	Receptor Number	Receptor Location	Land Use Type
1	301 East 7th Street	Commercial	24	325 Prince Charles Street	Residential
2	301 East 8th Street	Commercial	25	321 Prince Charles Street	Residential
3	301 East 9th Street	Commercial	26	317 Prince Charles Street	Residential
4	311 East 12th Street	Residential	27	5500 North Tryon Street/US-29	Commercial
5	430 East 36th Street	Industrial	28	5636 North Tryon Street/US-29	Commercial
6	407 East 36th Street	Industrial	29	5655 North Tryon Street/US-29	Commercial
7	3327 North Davidson Street	Industrial	30	5703 North Tryon Street/US-29	Commercial
8	501 Patterson Street	Residential	31	5732 North Tryon Street/US-29	Commercial
9	3440 North Davidson Street	Residential	32	5901 North Tryon Street/US-29	Residential
10	500 Herrin Avenue	Residential	33	5911 North Tryon Street/US-29	Hotel/Motel
11	3510 North Davidson Street	Residential	34	6001 North Tryon Street/US-29	Hotel/Motel
12	3528 North Davidson Street	Residential	35	6426 North Tryon Street/US-29	Hotel/Motel
13	601 East Sugar Creek Road	Industrial	36	110 West Rocky River Road	Hotel/Motel
14	4300 Raleigh Street	Industrial	37	7706 North Tryon Street/US-29	Hotel/Motel

Table 1 (continued)
Summary of potential construction noise impact prior to mitigation

Receptor Number	Receptor Location	Land Use Type	Receptor Number	Receptor Location	Land Use Type
15	352 Leafmore Drive	Residential	38	8001 North Tryon Street/US-29	Commercial
16	358 Leafmore Drive	Residential	39	132 East McCullough Drive	Hotel/Motel
17	364 Leafmore Drive	Residential	40	8404 North Tryon Street/US-29	Commercial
18	331 Barrymore Drive	Residential	41	8419 North Tryon Street/US-29	Hotel/Motel
19	332 St. Anne Place	Residential	42	8503 North Tryon Street/US-29	Hotel/Motel
20	341 Prince Charles Street	Residential	43	8517 North Tryon Street/US-29	Hotel/Motel
21	337 Prince Charles Street	Residential	44	8926 J.M.Keynes Drive	Commercial
22	333 Prince Charles Street	Residential	45	9321 JW Clay Boulevard	Commercial
23	329 Prince Charles Street	Residential			

Construction equipment that may generate significant vibration includes dump trucks, concrete mixers, auger drilling, impact pile driving, sonic pile driving and vibratory rollers. The primary concern for vibration from construction activities is potential structural damage to buildings. Potential vibration impact from construction activities has been assessed at all properties in close proximity to construction activities associated with the LYNX BLE. In addition, potential short-term impact to vibration sensitive equipment has been assessed. The sensitivity of a structure to potential damage depends primarily on the building's construction (i.e. reinforced concrete or non-engineered timber) The following are the range of distances that potential structural damage may occur from construction equipment for the range of different building construction types.

- Potential structural damage may occur within seven to 18 feet of buildings from large bulldozers, dump trucks, concrete mixers and hoe rams.
- Potential structural damage may occur within one to two feet of buildings from small bulldozers.
- Potential structural damage may occur within eight to 20 feet of buildings from auger drilling.
- Potential structural damage may occur within 14 to 34 feet of buildings from vibratory roller compaction.
- Potential structural damage may occur within 29 to 73 feet from impact pile driving and within 13 to 31 feet from sonic pile driving.

Table 2 presents the locations that certain construction equipment may potentially cause structural damage prior to mitigation (Appendix F, Figures 9a and 9b). Table 3 presents the locations that certain construction equipment may potentially impact vibration-sensitive equipment at UNC Charlotte CRI (Appendix F, Figure 9b).

Table 2
Summary of potential for structural damage from construction vibration

Receptor Location	Property	Building Construction	Construction Equipment
301 East 7th Street	Philip Carey Company Warehouse (Historic Property)	Engineered Masonry	Vibratory Roller
301 East 9th Street	Commercial Building (Multiple Occupants)	Engineered Masonry	Large Bulldozer, Auger Drilling, Vibratory Roller, Impact Pile Driver, Sonic Pile Driver
430 East 36th Street	Grinnell Manufacturing Company (Historic Property)	Engineered Masonry	Large Bulldozer, Auger Drilling, Vibratory Roller, Impact Pile Driver, Sonic Pile Driver
300 East 36th Street	Parish and Leonard Tire Company	Engineered Masonry	Vibratory Roller, Impact Pile Driver, Sonic Pile Driver
315 East 36th Street	Herrin Brothers Coal & Ice Company Complex (Historic Property)	Engineered Masonry and Metal	Vibratory Roller, Impact Pile Driver, Sonic Pile Driver
407 East 36th Street	Johnston Mill (Historic Property)	Engineered Masonry and Timber	Vibratory Roller, Impact Pile Driver, Sonic Pile Driver
3327 North Davidson Street	Mecklenburg Mill (Historic Property)	Engineered Masonry	Impact Pile Driver
601 East Sugar Creek Road	Republic Steel Corporation Plant (Historic Property)	Engineered Masonry	Vibratory Roller, Impact Pile Driver, Sonic Pile Driver
4300 Raleigh Street	State Industries	Engineered Masonry	Impact Pile Driver
332 St. Anne Place	Single-family Residence	Timber	Impact Pile Driver

Table 3
Summary of potential impact to sensitive equipment from construction vibration

Receptor Location	Construction Equipment
UNC Charlotte Bioinformatics	Impact Pile Driver
UNC Charlotte Duke Centennial Hall	Impact Pile Driver, Sonic Pile Driver
UNC Charlotte Grigg Hall	Impact Pile Driver, Sonic Pile Driver
UNC Charlotte EPIC Building	Impact Pile Driver

1.6 Construction Noise and Vibration Mitigation

Construction activities will be carried out in compliance with all applicable local noise regulations including the City of Charlotte Noise Ordinance and FTA guidelines for limiting construction vibration and the potential for structural damage to nearby buildings or impact to vibration-sensitive equipment. The contractors shall prepare a Construction Noise and Vibration Control Plan which specifies where and what type of construction equipment and methods will be used, predicts construction noise and vibration levels at locations where potential impact may occur and presents mitigation measures that will be implemented to minimize potential impact. The contractors will conduct noise and vibration monitoring at locations where potential impact from construction activities may occur. The contractors shall conduct pre-construction and post-construction surveys of buildings with the potential for structural damage identified in Section 6.9.

- Typical construction noise control measures include the following:
  - The location of construction equipment plays a critical role in potential impact at sensitive receptors. Mitigation should include locating stationary construction equipment as far as possible from noise-sensitive sites.
  - Many types of construction equipment include diesel engines which can be the most significant noise source. Therefore, reducing engine noise is often a key element to mitigating potential impact. Mitigation for engine noise may include use of shields, shrouds or intake and exhaust mufflers.
  - Most wheeled and tracked construction equipment is required to have back-up alarms for safety purposes. Due to their tonal character, these alarms are often a significant concern for noise impact. Special back-up alarms may be implemented including ambient-adjusted alarms which only sound five decibels higher than ambient conditions or “quackers” which have a less tonal character.
  - The use of steel plates on roadways can increase noise and vibration levels. Mitigation may include detouring traffic around plates, using thicker plates or placing a resilient material such as rubber under the plates.
  - Construction vehicles such as dump trucks and concrete mixers often contribute significantly to the noise conditions. Mitigation may include re-routing truck routes to minimize exposure to sensitive receptors.
  - Acoustic enclosures may be needed to reduce emissions from small construction equipment such as jackhammers and generators.
  - Temporary noise barriers or noise blankets can be installed between construction equipment and sensitive receptors to provide significant noise reduction (typically five to 15 decibels).
  - Generators can be a significant contributor to noise emissions. Noise mitigation may include limiting the size of generators, the locations they may be placed and/or the duration of their use.
  - Impact noise from dropping materials during loading and unloading activities can generate brief, but high noise levels. To reduce impact noise, lining chutes and bins with sound-deadening material such as rubber mats can significantly reduce noise.
  - Breaking up pavement and concrete can generate significant noise emissions. To mitigate potential noise impact, using concrete crushers or pavement saws rather than hoe rams can reduce noise. In addition increasing the number of perpendicular saw cuts can further reduce noise.
- Mitigation for potential vibration impact from construction activities includes utilizing specific construction equipment or methods. Typical construction vibration control measures include the following:
  - To mitigate potential construction vibration impact from large bulldozers or backhoes, small bulldozers can be used in almost all situations without potential vibration impact.
  - To mitigate potential impact associated with the use of a vibratory roller to compact soil, a static roller can be used which generates significantly less vibration.
  - Impact and sonic sheet pile driving can generate significant vibration. To mitigate potential construction vibration impact for retaining wall construction, a gravity or cantilevered retaining wall could be used since construction of these

types of walls primarily involve excavation rather than pile driving. If sheet piling is required, low-vibration sheet piling methods should be used such as those that use hydraulic push-in equipment. If retaining walls are constructed with soil nailing methods, drilling for the insertion of steel reinforcing elements would generate less vibration than impact of sonic sheet pile driving.

- For mitigation of potential vibration impact from pier pile driving for bridge construction, piers can be drilled in to generate significantly less vibration.
- Using truck routes that minimize exposure to sensitive receptors and maintaining smooth roadway surfaces.

2.0 ENVIRONMENTAL NOISE AND VIBRATION BASICS

2.1 Noise Fundamentals and Descriptors

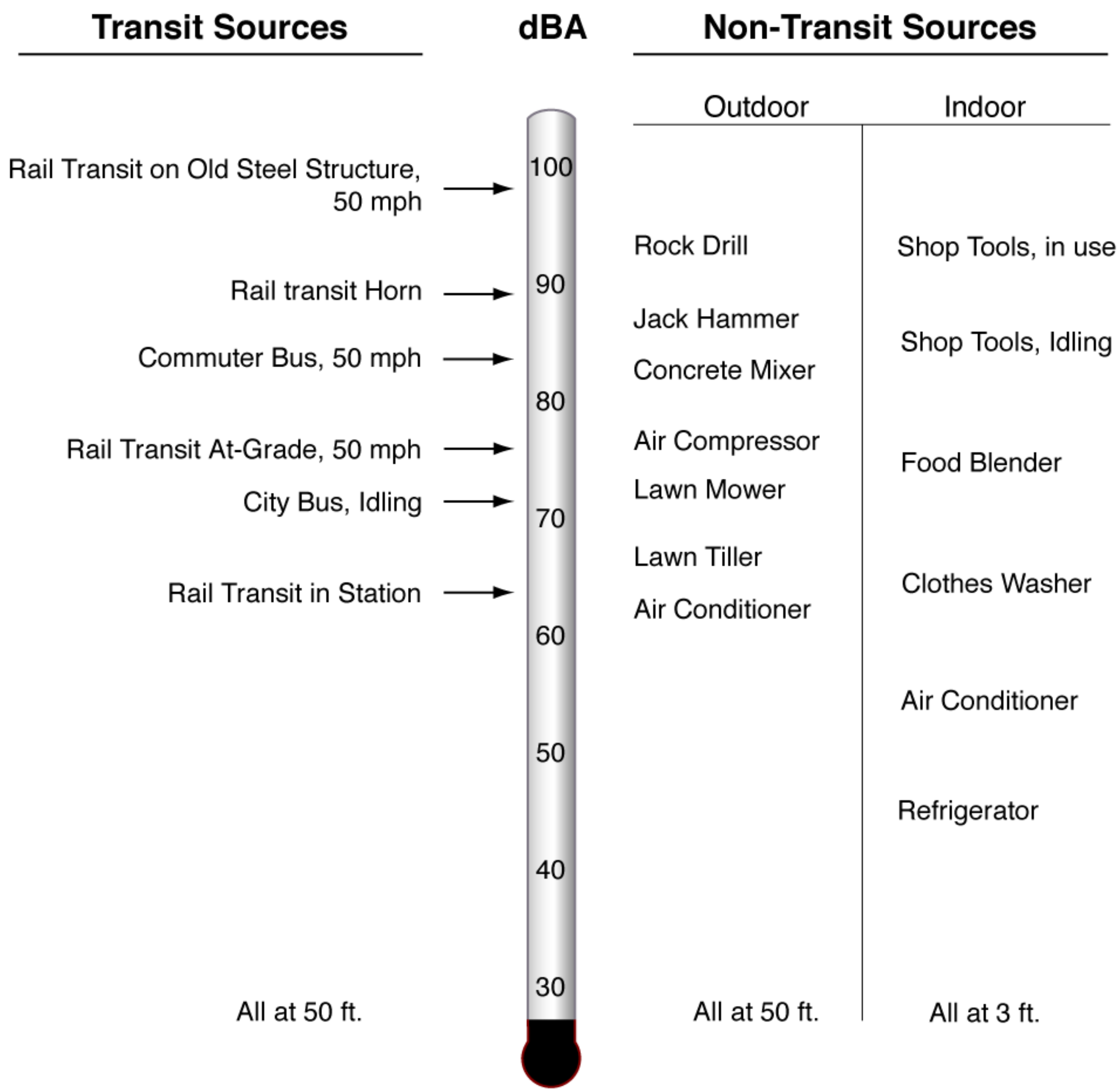
Noise is typically defined as unwanted or undesirable sound, where sound is characterized by small air pressure fluctuations above and below the atmospheric pressure. The basic parameters of environmental noise that affect human subjective response are (1) intensity or level, (2) frequency content and (3) variation with time. The first parameter is determined by how greatly the sound pressure fluctuates above and below the atmospheric pressure, and is expressed on a compressed scale in units of decibels. By using this scale, the range of normally encountered sound can be expressed by values between 0 and 120 decibels. On a relative basis, a 3-decibel change in sound level generally represents a barely noticeable change outside the laboratory, whereas a 10-decibel change in sound level would typically be perceived as a doubling (or halving) in the loudness of a sound.

The frequency content of noise is related to the tone or pitch of the sound, and is expressed based on the rate of the air pressure fluctuation in terms of cycles per second (called Hertz and abbreviated as Hz). The human ear can detect a wide range of frequencies from about 20 Hz to 17,000 Hz. However, because the sensitivity of human hearing varies with frequency, the “A-weighting system” is commonly used when measuring environmental noise to provide a single number descriptor that correlates with human subjective response. Sound levels measured using this weighting system are called "A-weighted" sound levels, and are expressed in decibel notation as "dBA." The A-weighted sound level is widely accepted by acousticians as a proper unit for describing environmental noise. To indicate what various noise levels represent, Figure 1 shows typical A-weighted sound levels for both transit and non-transit sources. As indicated in this figure, most commonly encountered outdoor noise sources generate sound levels within the range of 60 dBA to 90 dBA at a distance of 50 feet.

Because human perception of noise depends on how loud events are, how often they occur and how long they last, it is common practice to condense all of this information into a single number, called the “equivalent” sound level (Leq). Leq can be thought of as the steady sound level that represents the same sound energy as the varying sound levels over a specified time period (typically 1 hour or 24 hours). Human perception of noise also depends on what time of day events occur. Events which occur at night are of greater concern than those occurring during the day. The Day-Night Sound Level (Ldn) is the Leq value over a 24-hour period with an added 10-decibel penalty imposed on noise that occurs during the nighttime hours (between 10 P.M. and 7 A.M.). Many surveys have shown that Ldn is well correlated with human annoyance, and therefore this descriptor is widely used for environmental noise impact assessment. The use of Ldn and Leq to assess potential noise impact is discussed in Section 3.2.

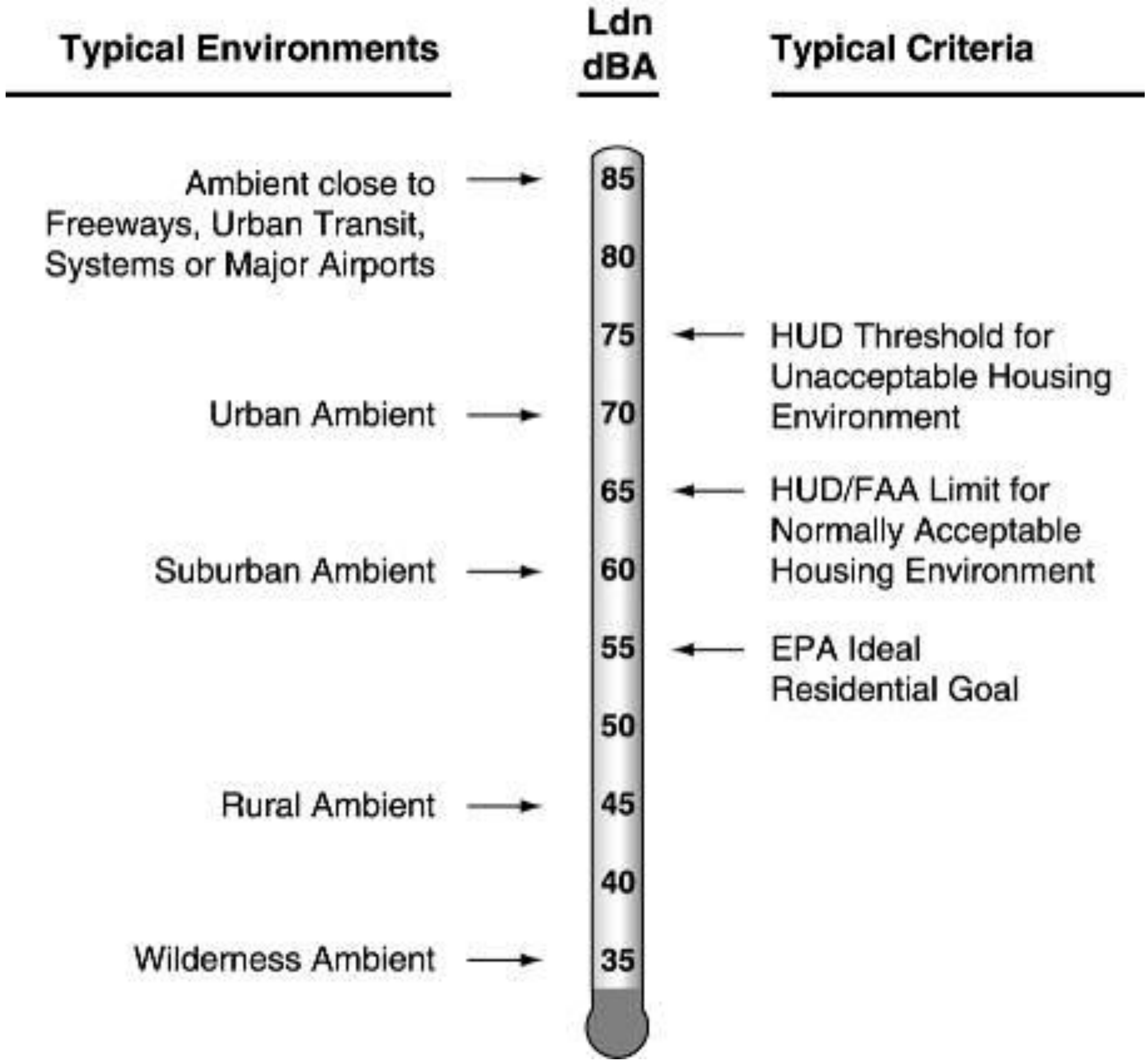
Figure 2 provides examples of typical noise environments and criteria in terms of Ldn. While the extremes of Ldn are shown to range from 35 dBA in a wilderness environment to 85 dBA in noisy urban environments, Ldn is generally found to range between 55 dBA and 75 dBA in most communities. As shown in Figure 2, this spans the range between an "ideal" residential environment and the threshold for an unacceptable residential environment according to some U.S. Federal agencies criteria.

Figure 1
Typical A-Weighted Sound Levels



Source: HMMH, 2011.

Figure 2
Examples of outdoor noise exposure



Source: HMMH, 2011.

2.2 Ground-Borne Noise and Vibration Fundamentals and Descriptors

Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because human sensitivity to vibration typically corresponds to the amplitude of vibration velocity within the low-frequency range of most concern for environmental vibration (roughly four to 80 Hz), velocity is the preferred measure for evaluating ground-borne vibration from transit projects.

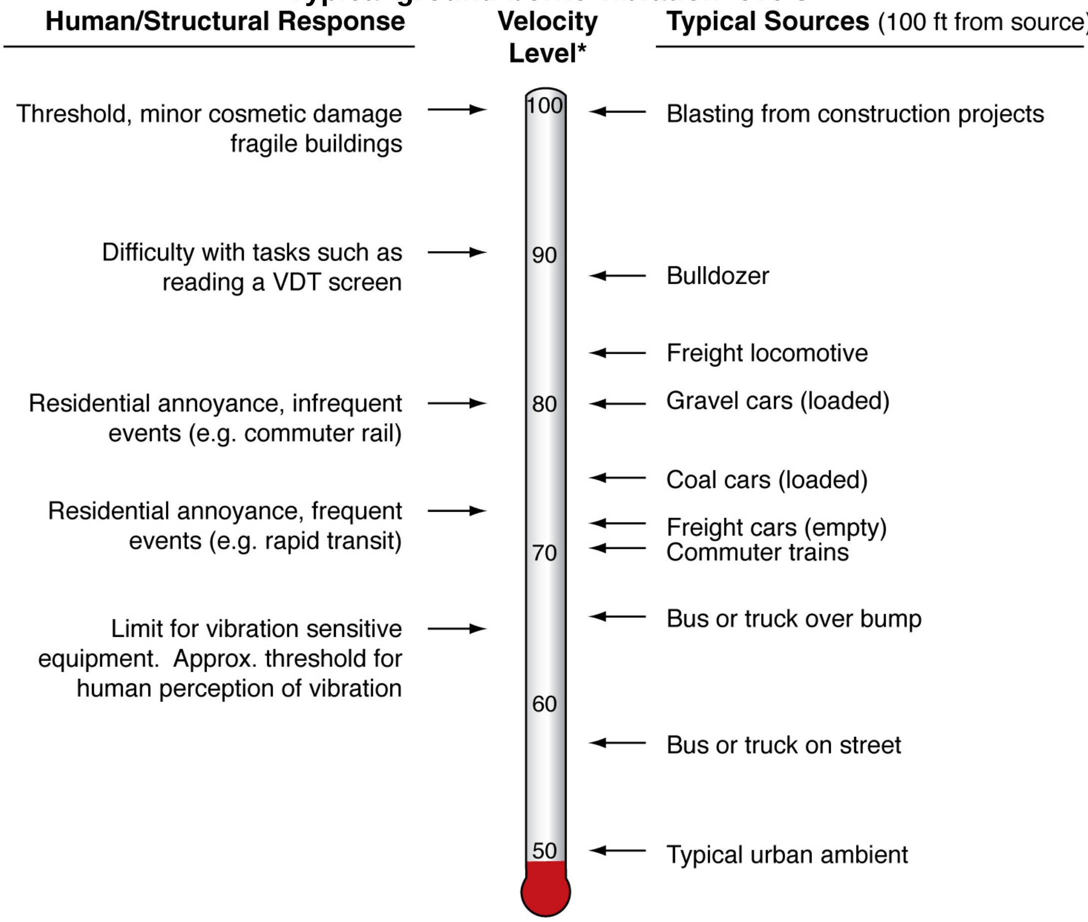
Vibration levels are generally measured and predicted in the vertical orientation. Vertical vibration at the ground surface typically exceeds the vibration in other axes since the stiffness of building floors is generally higher horizontally than vertically. To characterize existing conditions, however, ambient measurements, such as those near vibration-sensitive equipment, are often conducted in three directions (vertical and two horizontal).

Ground-borne vibration is typically characterized in terms of the “smoothed” root-mean-square (RMS) vibration velocity level, in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels. Vibration level in terms of RMS velocity has been found to correlate most suitably to human response to vibration in buildings and is the metric commonly used in U.S. and International standards.

Ground-borne vibration can also be characterized in terms of the peak particle velocity (PPV), defined as the maximum instantaneous peak of the vibratory motion and measured in inches per second. PPV is typically used in monitoring blasting and other types of construction-generated vibration, since it is related to the stresses experienced by building components. Therefore, for assessing potential vibration damage to structures, vibration levels are presented both in RMS velocity decibels (VdB) and PPV levels (in/s).

Figure 3 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to ground-borne vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human perception to vibration is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.

Figure 3
Typical ground-borne vibration levels



** RMS Vibration Velocity Level in VdB relative to 10^{-6} inches/second*

Source: HMMH, 2011.

Ground-borne noise is produced when ground-borne vibration propagates into a room and radiates noise from the motion of the surfaces. The room surfaces essentially act like a giant loudspeaker from the vibration. Ground-borne noise is perceived as a low frequency rumble and is generally considered only when airborne paths are not present (e.g. train inside a tunnel or a large masonry building with no windows or other openings to the outdoors). Ground-borne noise is assessed according to the A-weighted sound level in dBA. As presented in the following section, there are separate noise criteria for potential impact from airborne noise versus ground-borne noise. Since the proposed LYNX BLE does not have any significant tunnel sections and there are no sensitive locations without windows or other openings to the outdoors, ground-borne noise has not been assessed.

3.0 NOISE AND VIBRATION IMPACT CRITERIA

The FTA has noise and vibration impact criteria which are used to assess potential impact from long-term transit operations and short-term construction activities. Noise impact criteria are based on human annoyance from transit operations and construction and depend on the type of land use. Vibration impact criteria include those used to assess potential impact in terms of human annoyance and criteria used to assess the potential for damage to structures. The following sections describe the categorization of noise and vibration-sensitive land use according to FTA and the criteria used to assess potential impact.

3.1 Noise and Vibration-Sensitive Land Use Categories

For long-term noise exposure to transit operations, the FTA classifies noise-sensitive land uses into the following three categories.

- **Category 1**: Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.

- **Category 2**: Residences and buildings where people normally sleep. This category includes homes, hospitals, and hotels where a nighttime sensitivity is assumed to be of utmost importance.

- **Category 3**: Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, theaters, and places of worship 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 parks with passive recreation can also be considered to be in this category.

For short-term construction activities, noise-sensitive land use is categorized differently than for long-term operations. Potential noise impact from construction activities is assessed at residential land uses, similar to Category 2 above, as well as at commercial and industrial properties.

For long-term transit operations, the FTA classifies vibration-sensitive land uses into three categories similar to those for noise. However, because vibration is only assessed inside buildings, outdoor land uses (e.g. parks) are not considered to be vibration sensitive. In addition to the potential for human annoyance from vibration, vibration impact is also assessed for certain sensitive equipment. The land use categories for vibration are as follows:

- **Vibration Category 1**: High Sensitivity: Included in this category are buildings where vibration would interfere with operations. Vibration levels may be well below those associated with human annoyance. These buildings include vibration-sensitive research and manufacturing facilities, hospitals with sensitive equipment and university research operations. The sensitivity to vibration is dependent on the specific equipment present. Some examples of sensitive equipment include electron-scanning microscopes, magnetic resonance imaging scanners and lithographic equipment.

- **Vibration Category 2**: Residential: Residences and buildings where people normally sleep. This category includes homes, hospitals and hotels.

- **Vibration Category 3**: Institutional: This category includes buildings with primarily daytime and evening use. This category includes schools, libraries and churches.

There are some buildings, such as concert halls, recording studios and theaters that can be very sensitive to noise and/or vibration but do not fit into any of the three categories. Due to the sensitivity of these buildings, they usually warrant special attention during the environmental assessment of a transit project. Potential ground-borne vibration and ground-borne noise impact are assessed based on specific criteria for these special-use buildings.

Historic properties are sensitive to noise and vibration from transit operations based on the land use activities per the FTA categories. For example, historical buildings used as residences are assessed for potential impact according to Category 2 and historical buildings used for meditation, study or museums fall into Category 3. If historical buildings are used for commercial or industrial purposes they are not considered sensitive to noise or vibration from transit operations.

Potential vibration impact that could cause damage to structures is assessed at all buildings regardless of the nature of their use (i.e. residential, institutional, commercial or industrial). Very rarely do vibration levels from transit operations approach levels that could cause even minor cosmetic damage to structures. Therefore, potential damage to structures is generally only assessed for construction activities (i.e. pile driving, vibratory compaction and bull dozers). Further details on construction vibration criteria are presented in Section 3.5.

3.2 Noise Impact Criteria for Transit Operations

The FTA airborne noise impact criteria for long-term transit operations are founded on well-documented research on community reaction to noise and are based on the future change in noise exposure using a sliding scale. At locations with higher levels of existing noise, greater levels of noise due to the project are allowed.

Ldn is used to characterize noise exposure for locations with nighttime sensitivity (Category 2). For institutional land uses with primarily daytime use, such as amphitheaters and school buildings (Categories 1 and 3), the peak-transit hour Leq during the facility's operating period is used. Ldn and Leq are explained in Section 2.1.

There are two levels of impact included in the FTA criteria, as summarized below:

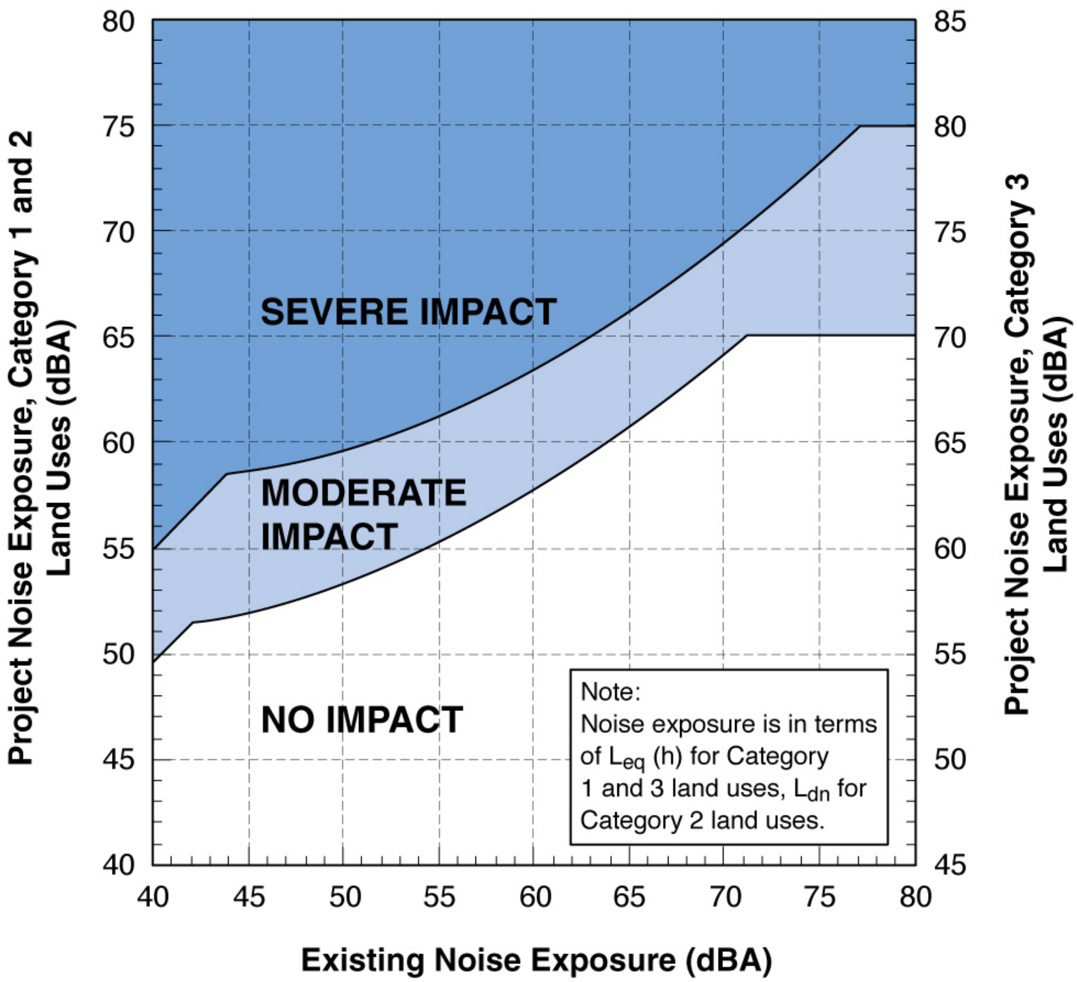
- **Severe Impact**: Project-generated noise in the severe impact range can be expected to cause a significant percentage of people to be highly annoyed by the new noise and represents the most compelling need for mitigation. Noise mitigation will normally be specified for severe impact areas unless there are truly extenuating circumstances that prevent it.

- **Moderate Impact**: In this range of noise impact, the change in the cumulative noise level is noticeable to most people but may not be sufficient to cause strong, adverse reactions from the community. In this transitional area, other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation.

These factors include the existing noise level, the predicted level of increase over existing noise levels, the types and numbers of noise-sensitive land uses affected, the noise sensitivity of the properties, the effectiveness of the mitigation measures, community views and the cost of mitigating noise to more acceptable levels.

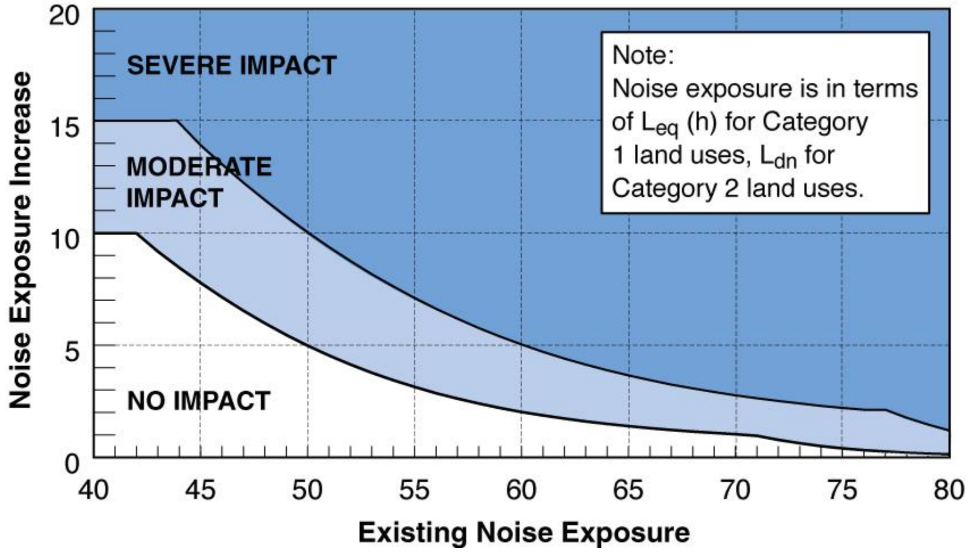
The FTA noise impact criteria used in this assessment are shown in graphical form in Figure 4 and Figure 5. Along the horizontal axis of Figure 4 is the existing noise exposure and the vertical axis shows the noise exposure due to project sources that would cause either moderate or severe impact. As the existing noise levels increase, a greater level of noise from project-related sources is allowed. FTA noise impact criteria can also be assessed by comparing existing noise conditions to future noise conditions, where future noise includes existing noise sources and project noise. This approach is necessary when the project would change existing noise sources such as shifting or adding lanes of roadway traffic or modifying existing train operations. Figure 5 presents the noise impact criteria based on future noise conditions. This figure shows existing noise conditions on the horizontal axis and the increase in future conditions on the vertical axis. As the existing noise levels increase, lesser noise increases are allowed.

Figure 4
FTA noise impact criteria based on project noise



Source: FTA Guidance Manual, 2006.

Figure 5
FTA noise impact criteria based on future noise



Source: FTA Guidance Manual, 2006.

3.3 Ground-Borne Noise and Vibration Impact Criteria for Transit Operations

The FTA ground-borne noise and vibration impact criteria for long-term transit operations are based on land use and train frequency, as shown Table 4. There are some buildings, such as concert halls, recording studios and theaters that can be very sensitive to vibration but do not fit into any of the three categories listed in Table 4. Due to the sensitivity of these buildings, they usually warrant special attention during the environmental assessment of a transit project. Table 5 gives criteria for acceptable levels of ground-borne vibration for various types of special buildings.

There are separate FTA criteria for ground-borne noise, the “rumble” that can be radiated from the motion of room surfaces in buildings due to ground-borne vibration. Such criteria are particularly important for underground transit operations. However, because airborne noise tends to mask ground-borne noise from above ground (i.e. at-grade or elevated) rail systems, ground-borne noise levels are generally only assessed in buildings without significant airborne noise paths.

In addition to the criteria provided in Table 4 and Table 5 for general assessment purposes, FTA has established criteria in terms of one-third octave band frequency spectra for use in detailed analyses. Table 6 and Figure 6 show the more detailed vibration criteria and the description of their use.

Table 4
FTA ground-borne noise and vibration impact criteria

Land Use Category	Ground-Borne Vibration Impact Criteria (VdB re: 1 micro-inch per second)			Ground-Borne Noise Impact Criteria (dBA re: 20 micro-Pascal)		
	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]
Category 1: Buildings where low ambient vibration is essential for interior operations.	65 VdB[4]	65 VdB[4]	65 VdB[4]	n/a[5]	n/a[5]	n/a[5]
Category 2: Residences and buildings where people normally sleep.	72 VdB	75 VdB	80 VdB	35 dBA	38 dBA	43 dBA
Category 3: Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB	40 dBA	43 dBA	48 dBA

[1] "Frequent Events" is defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.
[2] "Occasional Events" is defined as between 30 and 70 vibration events of the same kind per day. Most commuter rail trunk lines have this many operations.
[3] "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.
[4] 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.
[5] Vibration-sensitive equipment is generally not sensitive to ground-borne noise.

Source: FTA Guidance Manual, 2006.

Table 5
FTA ground-borne noise and vibration impact criteria for special buildings

Type of Building or Room	Ground-Borne Vibration Impact Criteria (VdB re: 1 micro-inch per second)		Ground-Borne Noise Impact Criteria (dBA re: 20 micro-Pascal)	
	Frequent Events	Occasional or Infrequent Events	Frequent Events	Occasional or Infrequent Events
Concert Halls	65 VdB	65 VdB	25 dBA	25 dBA
TV Studios	65 VdB	65 VdB	25 dBA	25 dBA
Recording Studios	65 VdB	65 VdB	25 dBA	25 dBA
Auditoriums	72 VdB	80 VdB	30 dBA	38 dBA
Theatres	72 VdB	80 VdB	35 dBA	43 dBA

Source: FTA Guidance Manual, 2006.

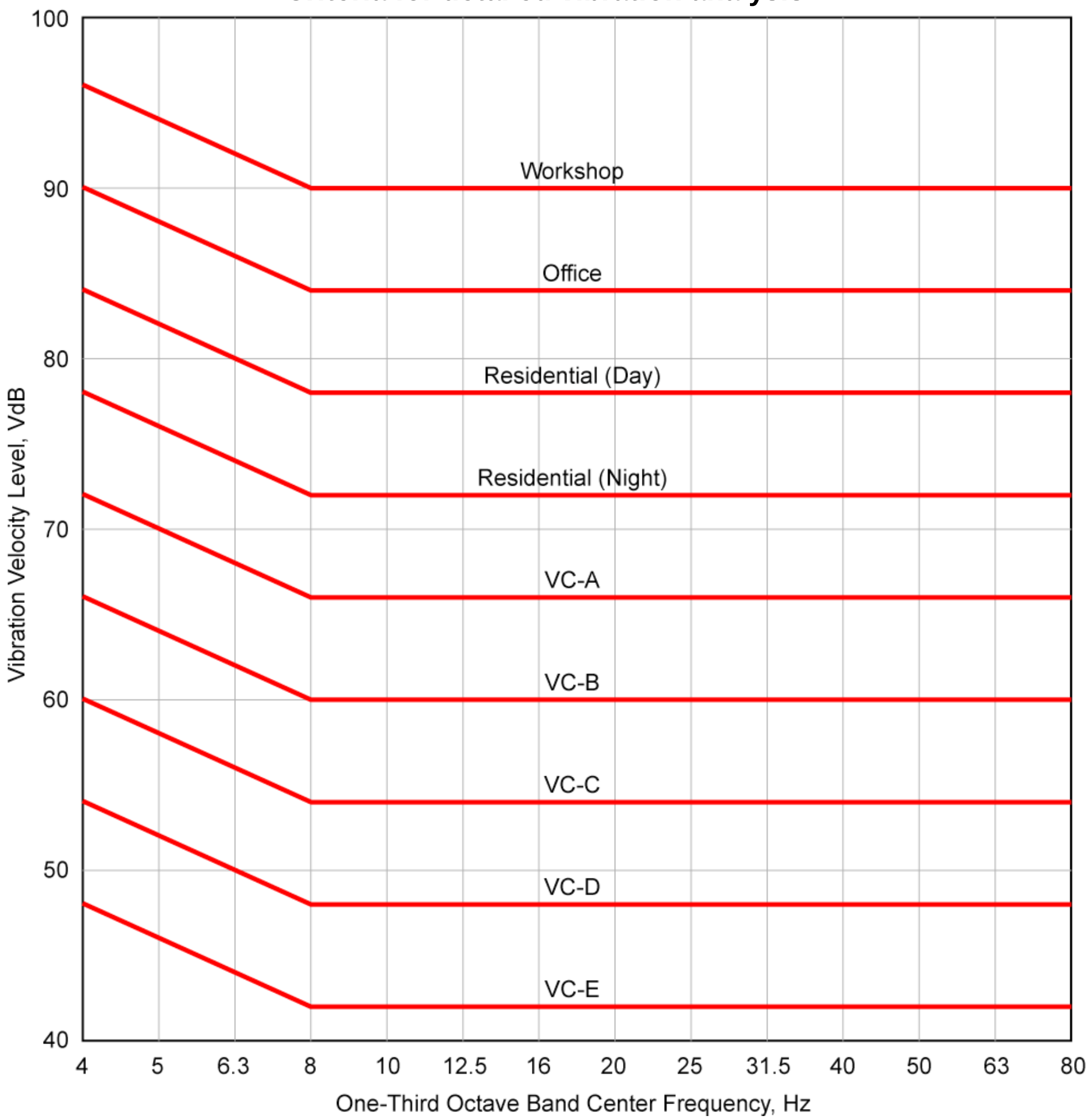
Table 6
Vibration criteria for detailed analysis

Criterion Curve	Maximum Vibration Level (VdB re: 1 micro-inch per second)	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

Source: FTA Guidance Manual, 2006.

For residential buildings, the applicable criterion for vibrations generated by LYNX BLE trains (frequent events) is a maximum velocity level of 72 VdB measured in any one-third octave band between four and 80 Hertz. For institutional buildings such as schools, libraries and churches, the applicable criterion for vibration generated from LYNX BLE trains is 75 VdB. Vibration-sensitive equipment at the CMC-University includes magnetic resonance imaging (MRI) scanners, CT scanners and microscopes. Equipment at the UNC Charlotte CRI includes scanning electron microscopes, atomic force microscopes, lithography equipment and metrology equipment. A summary of vibration criteria for sensitive equipment at CMC-University and the UNC Charlotte CRI are presented in Table 7.

Figure 6
Criteria for detailed vibration analysis



Source: FTA Guidance Manual, 2006.

Table 7
Vibration criteria for sensitive equipment at CMC - University and CRI

Equipment	Location	Vibration Sensitivity
Atomic Force Microscopic	CRI – Grigg Hall (Ground Floor)	VC-D
E-Beam Lithography	CRI – Grigg Hall (Ground Floor)	VC-E
Scanning Electron Microscope	CRI – Grigg Hall (Ground Floor)	VC-E
General Metrology Equipment	CRI – Grigg Hall (Ground Floor)	VC-D
Six-Axis Alignment System	CRI – Grigg Hall (Second Floor)	VC-B
Mask Aligner System	CRI – Grigg Hall (Third Floor)	VC-C
Stepper	CRI – Grigg Hall (Third Floor)	VC-E
General Lithography Equipment	CRI – Grigg Hall (Third Floor)	VC-D
Laser and Optical Setups	CRI – Grigg Hall (All Floors)	VC-C
Atomic Force Microscope	CRI – Duke Centennial Hall (Ground Floor)	VC-D
Diamond Turning Center	CRI – Duke Centennial Hall (Ground Floor)	VC-E
Diamond Machining Center	CRI – Duke Centennial Hall (Ground Floor)	VC-E
Scanning Electron Microscope	CRI – Duke Centennial Hall (Second Floor)	VC-E
Microarray Scanner	CRI – Bioinformatics (Third Floor)	VC-B[a]

a Vibration criterion for DNA Microarray is based on general specification of scanner with 5 or 10-micron pixel size.

3.4 Noise Impact Criteria for Construction Activities

Construction noise criteria are provided in Table 8 based on guidelines provided in the FTA Guidance Manual and the City of Charlotte Noise Ordinance. The FTA construction noise criteria are consistent with the City of Charlotte Noise Ordinance but provide a greater level of detail. The criteria are based on an 8-hour Leq noise level and depend on the type of land use and the time of day.

Table 8
Construction Noise Impact Criteria

Land Use	Noise Limit, 8-hour Leq (dBA)	
	Daytime (7 a.m. to 10 p.m.)	Nighttime (10 p.m. to 7 a.m.)*
Residential	80	70*
Commercial	85	85
Industrial	90	90

* City of Charlotte Noise Ordinance does not allow construction machinery to be used between 9:00pm and 7:00am in any part of the city zoned for residential use, or within 300 feet of any structure used as a residence regardless of its zoning. Nighttime construction restrictions do not apply to hotels and motels, so potential impact is assessed for nighttime residential land use.

Source: FTA Guidance Manual, 2006.

3.5 Vibration Impact Criteria for Potential Damage to Structures

Potential damage to structures from vibration depends on the type of building construction. Most buildings, including those which are historically significant, fall into Category I for reinforced-concrete, steel and timber structures or Category II for engineered-concrete and masonry structures. FTA criteria for potential structural damage are shown in Table 9. The criteria are presented in both vibration level (VdB) and PPV (in/s).

Table 9
Construction Vibration Impact Criteria

Building Category	Vibration Criteria for Potential Damage to Structures	
	Vibration Level (VdB)	Peak-Particle Velocity (in/s)
I. Reinforced-concrete, steel or timber	102	0.5
II. Engineered-concrete and masonry	98	0.3
III. Non-engineered timber and masonry	94	0.2
IV. Buildings extremely susceptible to vibration damage	90	0.12

Source: FTA Guidance Manual, 2006.

4.0 EXISTING NOISE AND VIBRATION CONDITIONS

Land use sensitive to noise and vibration from long-term transit operations near the proposed alignment includes residential properties, hotels, motels, mobile homes, schools, churches and medical facilities. Sensitive land use was identified by Charlotte-Mecklenburg Geographical Information System (GIS) Zoning Data and field observations conducted in October 2010. The following describes some of the sensitive land use that would be close to the proposed alignment, along with the existing noise and vibration conditions at those locations based on the measurement results included in Section 5 below.

Sensitive land use between 7th Street and I-277 includes the ImagineOn library at 300 East 7th Street, the First United Presbyterian Church at 201 East 7th Street, a 10-floor high rise UNC Charlotte multi-use building (under construction) at 320 East 9th Street and governmental offices at 618 North College Street. These receptors are 150 to 330 feet from the proposed alignment. A short-term (1-hour) existing noise measurement was conducted at the First United Presbyterian Church (Site 1). The measured peak-transit hour Leq was 63 dBA and the estimated Ldn was 61 dBA. Existing noise conditions are dominated by vehicular traffic at these sensitive receptors. Vibration line source transfer mobility was measured at East 11th Street and North Brevard Street (Site V-1). The measurement results are representative of the vibration propagation characteristics of the soil between the southern terminus of the proposed alignment and Parkwood Avenue.

The Alpha Mill Apartments at 311 East 12th Street north of I-277 are sensitive to noise and vibration. Three short-term (1-hour) existing noise measurements were conducted at this location (Site 2). The estimated Ldn at this receptor was 71 dBA. The existing noise conditions at the Alpha Mill Apartments are dominated by vehicular traffic on I-277 and 12th Street and railroad activity on the CSX and Norfolk Southern railroads.

Sensitive land use between 16th Street and North Brevard Street includes single-family residences on Parkwood Avenue and East 19th Street. Existing noise measurements include three short-term noise measurements at 234 Parkwood Avenue (Site 3) and a long-term (24-hour) noise measurement at 405 East 19th Street (Site 4). The measured Ldn at Site 4 was 69 dBA and the estimated Ldn at Site 3 was 73 dBA. Existing noise conditions at these locations are dominated primarily by vehicular traffic on Parkwood Avenue with contributions from the Norfolk Southern Intermodal Facility.

On North Brevard Street between Parkwood Avenue and Mallory Street, sensitive land use includes single-family residences set back on East 22nd Street and Charles Avenue and the Highland Mill Apartments at 2901 North Davidson Street. Existing noise measurements include three short-term noise measurements at 423 East 22nd Street (Site 5) and the Highland Mill Apartments (Site 7) and a short-term noise measurement during the peak-transit hour at 2604 North Brevard Street (Site 6) at the previous site of the GDR Holiness Church. The estimated Ldn's at Site 5 and Site 7 were 60 dBA and 63 dBA, respectively. The measured peak-transit hour Leq at Site 6 was 61 dBA. The existing noise conditions in this area are dominated by vehicular traffic on North Brevard Street with contributions from the Norfolk Southern mainline railroad. Vibration line source transfer mobility was measured at North Davidson Street and Herrin Avenue (Site V-2). The measurement results are representative of the vibration propagation characteristics of the soil between Parkwood Avenue and East 36th Street.

On North Davidson Street between East 36th Street and East Craighead Road, sensitive land use includes single-family residences on North Davidson Street, East 37th Street, Patterson Street and Herrin Avenue and multi-family residences including The Colony (mixed-use development) at 3440 North Davidson Street and the Renaissance Apartments on North Davidson Street. A long-term noise measurement was conducted at The Colony (Site 8). The measured Ldn at this location was 69 dBA. The existing noise conditions are dominated by vehicular traffic on North Davidson Street with contributions from the Norfolk Southern mainline railroad.

Sensitive land use between Sugar Creek Road and Eastway Drive includes single-family residences on Bearwood Avenue, Howie Circle, Leafmore Drive, Clintwood Drive, Barrymore Drive, St. Anne Place, Prince Charles Street and Eastway Drive, the Vietnamese Baptist Church on Howie Circle and the Carolinas Medical Center - North Park on Eastway Drive. Long-term noise measurements were conducted at 4031 Bearwood Avenue (Site 9) and 332 St. Anne Place (Site 10). Existing noise measurements were conducted approximately 75 feet from the Norfolk Southern mainline railroad at Site 9 and approximately 125 feet from the railroad at Site 10. The measured Ldn's were 76 dBA at Site 9 and 71 dBA at Site 10. The existing noise conditions are dominated by freight train and Amtrak train activity on the Norfolk Southern mainline railroad. Vibration line source transfer mobility was measured at the Carolinas Medical Center - North Park in the North Park Mall (Site V-3). The measurement results are representative of the vibration propagation characteristics of the soil between East 36th Street and North Tyron Street/US-29. Existing vibration measurements of freight trains and Amtrak commuter trains were also conducted at this site.

Sensitive land use on North Tryon Street/US-29 between Eastway Drive and the North I-85 Service Road includes the Crossroads Charter High School at 5500 North Tryon Street/US-29, Shady Grove Mobile Home Park at 400 Lambeth Drive, Pines Mobile Homes at 5635 North Tryon Street/US-29, the Harbor Baptist Church at 5801 Old Concord Road, the Holiday Motel at 6001 North Tryon Street/US-29 the Fairyland Learning Center at 6442 North Tyron Street and single-family residences on Northridge Village Drive, 6919 North Tyron Street and 6811 Kemp

Street. Existing noise measurements in this area include three short-term measurements at 400 Lambeth Drive (Site 11), two short-term measurements at the Crossroads Charter High School (Site 12), a long-term noise measurement at the Pines Mobile Park (Site 13), two short-term measurements at the Harbor Baptist Church (Site 14), a long-term noise measurement at the Holiday Motel (Site 15) and a long-term measurement at Northridge Village Drive (Site 16). The estimated Ldn's were 54 dBA, 70 dBA and 60 dBA at Site 11, Site 12 and Site 14, respectively. The measured Ldn's were 62 dBA, 70 dBA and 64 dBA at Site 13, Site 15 and Site 16, respectively. The existing noise conditions in this area are dominated by vehicular traffic on North Tryon Street/US-29.

On North Tryon Street/US-29 between the North I-85 Service Road and UNC Charlotte Research Drive, sensitive land use includes Intown Suites Hotels at 110 W. Rocky River Road And 7706 North Tryon Street/US-29, the Microtel Inn Hotel at 132 East McCullough Drive, the Hampton Inn at 8419 North Tryon Street/US-29, the Marriott Residence Inn at 8503 North Tryon Street/US-29 and the CMC-University at 8800 North Tryon Street/US-29 which includes hospital beds and vibration-sensitive equipment. A short-term noise measurement was conducted at the Intown Suites Hotel at 110 W. Rocky River Road (Site 17), three short-term measurements were conducted at the Marriott Residence Inn (Site 18) and a short-term measurement was conducted at CMC-University (Site 19). The estimated Ldn's at these measurement locations were 62 dBA, 66 dBA and 58 dBA, respectively. The existing noise conditions in this area are dominated by vehicular traffic on North Tryon Street/US-29. Vibration line source transfer mobility was measured at CMC-University (Site V-4). The measurement results are representative of the vibration propagation characteristics of the soil along North Tryon Street/US-29 between Eastway Drive and the UNC Charlotte campus.

Noise and vibration-sensitive buildings at UNC Charlotte CRI include the Bioinformatics building, Duke Centennial Hall, Grigg Hall, Laurel Hall, Witherspoon Hall, Spruce Hall and the EPIC building (under construction), with sensitive uses as follows:

- The Bioinformatics building, Duke Centennial Hall, Grigg Hall and EPIC building have classrooms and labs that are considered to be sensitive to noise as a Category 3 institutional land use.
- Laurel Hall, Witherspoon Hall and Spruce Hall are considered sensitive to noise as Category 2 land use (residential) receptors.
- Bioinformatics, Duke Centennial Hall and Grigg Hall contain the following equipment which are sensitive to vibration with sensitivities ranging from the VC-B to VC-E criteria:

    - A DNA Microarray (VC-B) on the second floor of the Bioinformatics building.
    - An atomic force microscope (VC-D), an E-beam lithography machine (VC-E) and a scanning electron microscope (VC-E) on the ground floor, general metrology equipment (VC-D) on the first floor, a six-axis alignment system (VC-B) on the second floor, a mask aligner system (VC-C), a stepper with built in vibration control (VC-E) and general lithography equipment (VC-D) on the third floor and laser and optical setups (VC-C) on all floors of Grigg Hall.
    - An atomic force microscope (VC-D), a diamond turning center (VC-E), a diamond machining center (VC-E), surface quality gauges, and metrology equipment on the ground floor (VC-D) and a scanning electron microscope (VC-E) on the second floor of Duke Centennial Hall.

A short-term noise measurement during the peak-transit hour was conducted at Duke Centennial Hall (Site 20) and a long-term noise measurement was conducted at Laurel Hall (Site 22). The measured peak-transit hour Leq was 65 dBA at Site 20 and the measured Ldn at

Site 22 was 62 dBA. Existing noise conditions at the UNC Charlotte campus were dominated by vehicular traffic on North Tryon Street/US-29 and campus roads. Existing ambient vibration measurements were conducted near vibration-sensitive equipment at the Bioinformatics building, Duke Centennial Hall and Grigg Hall. In general, ambient vibration conditions meet the VC-E criterion at most ground floor locations and the VC-B criterion at most upper floor locations. More details on the existing vibration conditions are presented in Section 5.5.5. Vibration line source transfer mobility was measured at the Hayes Recreational Field (Site V-5). The measurement results are representative of the vibration propagation characteristics of the soil at the UNC Charlotte campus.

5.0 NOISE AND VIBRATION MEASUREMENTS

5.1 Noise and Vibration Measurement Equipment

All noise measurement equipment used by Harris Miller Miller & Hanson Inc. (HMMH) conforms 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 were carried out in the field using acoustical calibrators. Table 10 presents a list of noise and vibration measurement equipment used including manufacturer, model and serial number.

Table 10
Noise and vibration measurement equipment list

Equipment	Manufacturer	Model	Serial Number
Sound Level Meter	Bruel & Kjaer	2250	2590436
Microphone	Bruel & Kjaer	4189	2589635
Calibrator	Bruel & Kjaer	4231	2579294
Sound Level Meter	Larson Davis	820	1286
Microphone	GRAS	40AQ	16979
Calibrator	Quest	QC-20	QF8040011
Digital Recorder	TEAC	LX-110	535142
Accelerometer	PCB	393A	4739
Accelerometer	PCB	393A	5394
Accelerometer	PCB	393A	5397
Accelerometer	PCB	393A	5730
Accelerometer	PCB	393C	10001
Accelerometer	PCB	393C	10002
Accelerometer	PCB	T356M98	83168
Accelerometer	PCB	T356M98	83182
Accelerometer	PCB	T356M98	102929
Load Cell	Honeywell/Sensotec	Type 41	1133547

5.2 Noise Measurement Methodology

5.2.1 Existing Noise Measurements

Measurements to characterize the existing noise environment in the study area were conducted at noise-sensitive receptors. Both long-term (24-hour) and short-term (1-hour) noise measurements were conducted at representative locations. Long-term measurements provide a direct measurement of both Ldn and peak transit-hour Leq. Short-term measurements typically provide a direct measurement of peak transit-hour Leq and estimated Ldn levels based on methods described in the FTA guidance manual.

Noise impact is typically assessed for outdoor land uses at the nearest building façade or areas of frequent human use such as patios or pools. Noise measurement sites were selected based on the location of noise-sensitive land use along the proposed corridor, the proximity to the proposed alignment and the surrounding terrain. The distance from the measurement location to dominant noise sources (i.e. railroad or streets) was chosen to be representative of typical noise-sensitive locations in each area. The microphone was positioned to characterize the exposure of the site to the dominant noise sources in the area.

5.2.2 Reference Source Level Measurements

Source level measurements were conducted of the principal noise sources associated with the proposed project. These noise sources include CATS Blue Line light rail vehicles (LRVs) operating without horns or bells, while sounding the low horn through grade-crossings, on tight-radius curves and stationary with auxiliary equipment running. Reference noise measurements were also conducted of the train's audible warning devices, grade-crossing bells and a traction power substation. Measurements were conducted at a specific setback distance (typically 25 or 50 feet) from the track centerline or stationary noise source location. The speeds, consists and other operational information of the trains were documented and photographs were taken of the noise sources.

5.3 Vibration Measurement Methodology

5.3.1 Vibration Propagation and Vehicle Force Density Measurements

Vibration propagation measurements were made to characterize the efficiency with which vibration propagates from the train sources to nearby sensitive buildings. These measurements, in conjunction with vehicle force density measurements, are used to project future vibration levels. The measurements were conducted with high-sensitivity accelerometers mounted in the vertical direction on either paved surfaces, or on top of steel stakes driven into soil. The acceleration signals were recorded on a TEAC Model LX-110 multi-channel digital recorder and subsequently analyzed using digital signal processing software.

The vibration propagation test procedure is shown schematically in Figure 7. As shown in the cross section view at the top, the test basically consists of dropping a 60 lb weight from a height of three to four feet onto the ground. A load cell is used to measure the force of the impact and accelerometers are used to measure the resulting vibration responses at various distances along the ground. The relationship between the input force and the ground surface vibration, called the transfer mobility, characterizes vibration propagation at a given location. It is then possible to estimate the ground vibration that would be caused by another source, such as a train, by substituting the train force for the impact force.

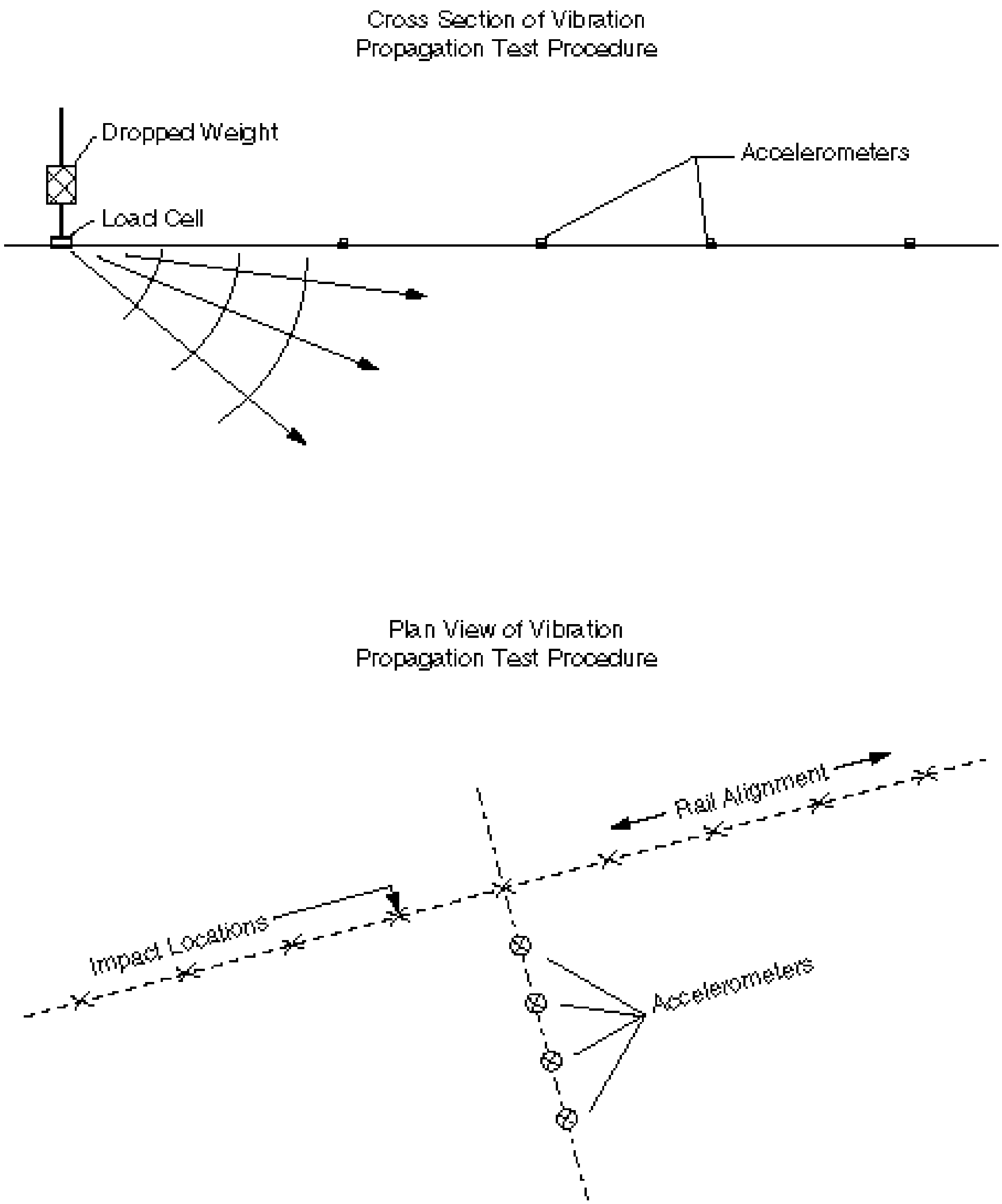
The bottom sketch in Figure 7 shows how the dropped weight point source is used to simulate a line vibration source such as a train. Impact tests are made at regular intervals in a line along the rail alignment. For these tests, impacts were typically done at eleven points, spaced 15 feet apart along a line perpendicular to the line of accelerometers. The measurement sites were selected to be open and free of buildings so as not to affect the vibration propagation conditions.

By measuring the line source transfer mobility at a given site and vibration levels of the CATS Blue Line trains at that same location, we calculate the vehicle force density with the following relationship:

$FD = L_v – LSTM$

Where FD is the vehicle force density, L_v is the measured train ground-borne vibration and LSTM is the line source transfer mobility at the reference site. Once a vehicle force density is calculated, it is then used to project future vibration levels by combining it with line source transfer mobility measurements at sites along the project corridor.

Figure 7
Vibration propagation test procedure



Source: HMMH, 2011.

5.3.2 Ambient Vibration Measurements

Although vibration criteria do not depend on existing conditions as noise criteria do, measuring the existing vibration conditions near vibration-sensitive equipment provides an indication of how existing conditions compare to the impact criteria for the equipment. Ambient vibration measurements were conducted by placing tri-axial accelerometers near sensitive equipment in the Bioinformatics building, Duke Centennial Hall and Grigg Hall. The three axes measured include vertical vibration, a horizontal direction oriented perpendicularly to the proposed alignment and a horizontal direction oriented transversely to the proposed alignment. Ambient levels were recorded for approximately five minutes and the range of vibration levels measured at each site were reported. Since ambient vibration levels vary from moment to moment, statistical metrics including the L10 (vibration level exceeded only 10 percent of the time), the L50 (median vibration level) and L90 (vibration level exceeded 90 percent of the time) were computed.

5.3.3 Vibration Measurements of Existing Amtrak and Freight Trains

Vibration measurements of existing Amtrak and freight trains were conducted to provide information on existing conditions associated with these sources. Measurements were conducted near the Carolinas Medical Center – North Park at distances of 85 to 225 feet from the near tracks. Although potential vibration impact does not depend on existing vibration conditions, these measurements provide an indication of the existing vibration levels at sensitive receptors along the North Carolina Railroad / Norfolk Southern (NCRR/NS) mainline.

5.4 Noise Measurement Results

5.4.1 Existing Noise Conditions

To characterize the existing noise conditions throughout the proposed corridor, measurements were conducted at 25 sites. The sites are described in Table 11 below and their locations are shown in Figure 1 and Figure 2 in Appendix E. These measurements were conducted by HMMH in 2005 and 2010 and by STV/ Ralph Whitehead Associates in 2008. These measurements include both long-term (24-hour) measurements and short-term (1-hour) measurements. Table 11 presents the results for all existing noise measurements.

Table 11
Summary of existing noise measurement results

Site	Measurement Location and Address	Date	Duration (hour)	Noise Level (dBA)	
				Existing Day-Night Average Sound Level (Ldn)	Existing Peak-Transit Hour Sound Level (Leq)
1	United Presbyterian Church 201 East 7th Street	10/04/2005*	1	61.0	63.0
2	Alpha Mill Apartments 311 East 12th Street	10/01/2008**	3	71.0	59.1
3	Single-family residence 234 Parkwood Avenue	10/01/2008**	3	72.7	73.9

Table 11 (continued)
Summary of existing noise measurement results

Site	Measurement Location and Address	Date	Duration (hour)	Noise Level (dBA)	
				Existing Day-Night Average Sound Level (Ldn)	Existing Peak-Transit Hour Sound Level (Leq)
4	Single-family residence 405 East 19th Street	10/03/2005*	24	69.0	69.0
5	Single-family residence 423 East 22nd Street	10/01/2008**	3	60.1	56.0
6	GDR Holiness Church 2604 North Brevard	10/04/2005*	1	59.0	61.0
7	Highland Mill Apartments 2901 North Davidson Street	10/01/2008**	3	63.1	61.3
8	The Colony (mixed-use) 3440 North Davidson Street	10/03/2005*	24	69.0	71.0
9	Single-family residence 4031 Bearwood Avenue	10/03/2005*	24	76.0	67.0
10	Single-family residence 332 St Anne Place***	12/15/2008**	24	71.4	58.8
11	Elmore Mobile Home Park 4832 North Tryon Street/US-29	10/02/2008**	3	53.8	50.2
12	Crossroads Charter High School 5500 North Tryon Street/US-29	10/02/2008**	2	69.6	71.8
13	Pines Mobile Park 5636 North Tryon Street/US-29	10/12/2010*	24	61.5	60.2
14	Harbor Baptist Church 5801 Old Concord Road	10/02/2008**	2	59.8	62.0
15	Holiday Motel 6001 North Tryon Street/US-29	10/03/2005*	24	70.0	68.0
16	Single-family residence 201 Kingville Drive	10/08/2008**	24	63.6	66.4
17	InTown Suites Motel 110 Rocky River Road	10/04/2005*	1	62.0	64.0
18	Marriott Residence Inn Hotel 8503 North Tryon Street/US-29	10/06/2008**	3	66.1	66.4
19	Carolinas Medical Center- University 8800 North Tryon Street/US-29	10/06/2008**	1	58.1	60.1
20	UNC Charlotte Duke Centennial Hall	10/06/2008**	1	63.3	65.3
21	Summitt Green Apartments 209 Barton Creek Drive	10/03/2005*	24	62.0	61.0
22	UNC Charlotte Laurel Hall	10/08/2008**	24	62.1	55.3
23	Mallard Creek Apartments 420 Michelle Linnea Drive	10/07/2008**	1	50.5	52.5
24	Hunt Club Apartments 208 Northbend Drive	10/04/2005*	1	63.0	65.0
25	Queen's Grant Mobile 124 Carnival Street	10/06/2008**	3	55.4	52.5

* Source: Harris Miller Miller and Hanson Inc.
** Source: STV Incorporated.
*** Property was previously identified as 342 St. Anne Place in Draft EIS.

5.4.2 Reference Source Level Results

Measurements of Siemens S70 LRVs operating on the existing South Corridor were conducted at Remount Road. These measurements include pass-bys between 45 and 55 mph with and without the use of low horns through a grade crossing. Measurements of the crossing bells were also conducted at this location. At the South Corridor Light Rail Vehicle Maintenance Facility, reference measurements were conducted of the LRV operating on a tight-radius curve (100 feet) at a low speed (approximately 5 mph). In addition to these measurements on a tight-radius curve at the maintenance facility, reference source levels were measured of potential wheel squeal from the Siemens S70 LRV operating on the Houston METRO Red Line on a 350-foot radius curve at approximately 20 mph. Reference measurements of a traction power substation were conducted along the existing Blue Line at East 10th Street.

The noise level results for the measured sources are as follows:

- A LRV (one car) operating at 50 mph and 50 feet without bells or horns generates a maximum noise level of 78 dBA and a SEL of 83 dBA.
- A LRV (one car) operating at 50 mph and 50 feet while sounding the low horn through a grade-crossing generates a maximum noise level of 82 dBA and a SEL of 91 dBA.
- A LRV (one car) operating on a tight-radius curve such as a 100-foot radius curve at 5 mph or a 350-foot radius curve at 20 mph generates a SEL of 92 dBA at a distance of 50 feet from the track. Measurements on a 100-foot radius curve were conducted at the South Corridor Light Rail Vehicle Maintenance Facility in Charlotte and measurements on a 350-foot curve were conducted on the Houston METRO Red Line.
- A LRV (one car) stationary with auxiliary equipment generates a SEL of 71 dBA for a 60-second dwell time at distance of 50 feet and maximum noise levels of 53 dBA (idle) and 61 dBA (air pressure release).
- The audible warning devices on the LRV generate a maximum noise level of 69 dBA for bells, 81 dBA for the low horn and 87 dBA for the high horn at a distance of 50 feet.
- The grade-crossing bells generate a maximum noise level of 73 dBA at a distance of 10 feet. The bells sound for approximately 50 seconds from the closing of the gates, through the train pass by until the gates have been lifted up. Each crossing bell (not including train pass by noise) generate a SEL of 76 dBA at a distance of 50 feet. Generally, there are two bells at each grade-crossing.
- A traction power substation (TPSS) enclosure at a distance of 50 feet generates a maximum noise level of 57 dBA and a SEL of 93 dBA based on continuous operation for a one-hour period.

5.5 Vibration Measurement Results

Table 12 summarizes the vibration measurement sites selected for the LYNX BLE project; Figure 1 and Figure 2 in Appendix E show their locations. The types of measurements included LSTM, force density of the Siemens S70 LRV, Amtrak and freight train pass bys and ambient measurements at UNC Charlotte CRI.

Table 12
Vibration measurement locations in study area

Measurement Site	Location	Type of Measurement
V-1	East 11th Street & Brevard Street	LSTM
V-2	North Davidson Street	LSTM
V-3	North Park Mall	LSTM / Amtrak / Freight
V-4	Carolinas Medical Center - University	LSTM
V-5	UNC Charlotte	LSTM / Ambient
V-6	Kirk Field Farms[1]	LSTM
FD	Remount Road	Force Density

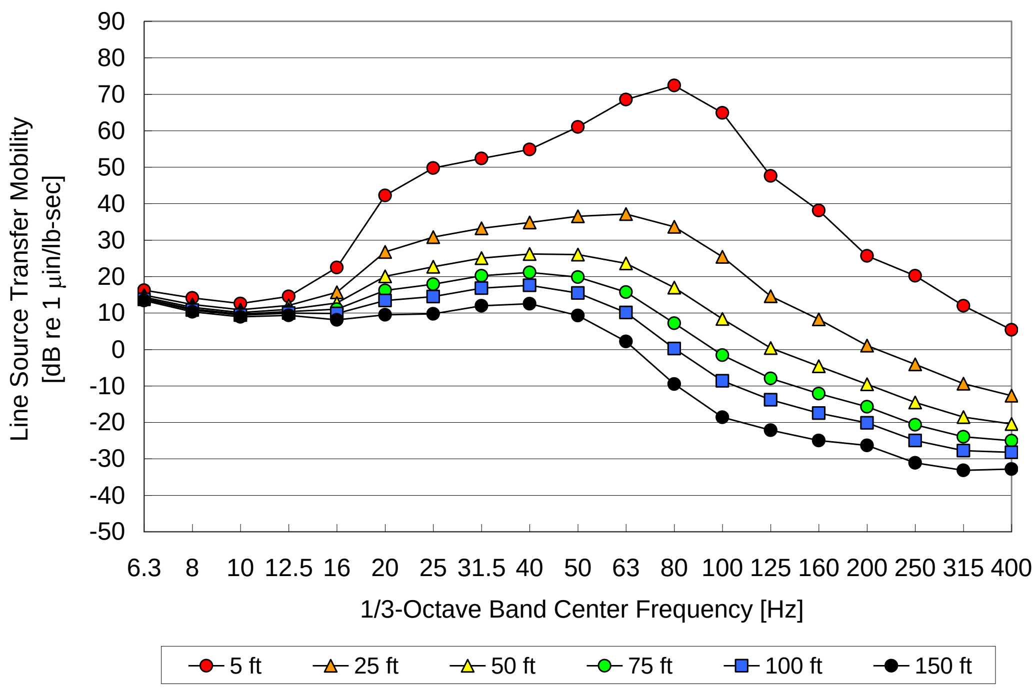
1 Measurements conducted at Kirk Farm Fields for alignment proposed in Draft EIS extending to I-485.

5.5.1 Vibration Propagation (Line Source Transfer Mobility) Results

Measurements of the vibration propagation conditions of the soil were measured at six locations along the proposed alignment and at the vehicle force density site on the South Corridor. The LSTM is representative of the vibration propagation characteristics for a three-car train.

Figure 8 shows the LSTM results from Site V-1 at East 11th Street and North Brevard Street. This figure shows the LSTM's at various distances from the line of impact positions. The difference between these LSTM lines indicate how much vibration will be reduced as it propagates from the train through the soil. This figure shows that vibration in the 80-Hz to 200-Hz frequency range exhibit the greatest reduction as a function of distance while low-frequency vibration below 20 Hz does not decrease as significantly with distance. Appendix B shows the LSTM results from all measurement locations for three-car trains, including the regression coefficients for calculating LSTM versus distance and plots of the results.

Figure 8
LSTM Results at Site 1: East 11th Street and North Brevard Street



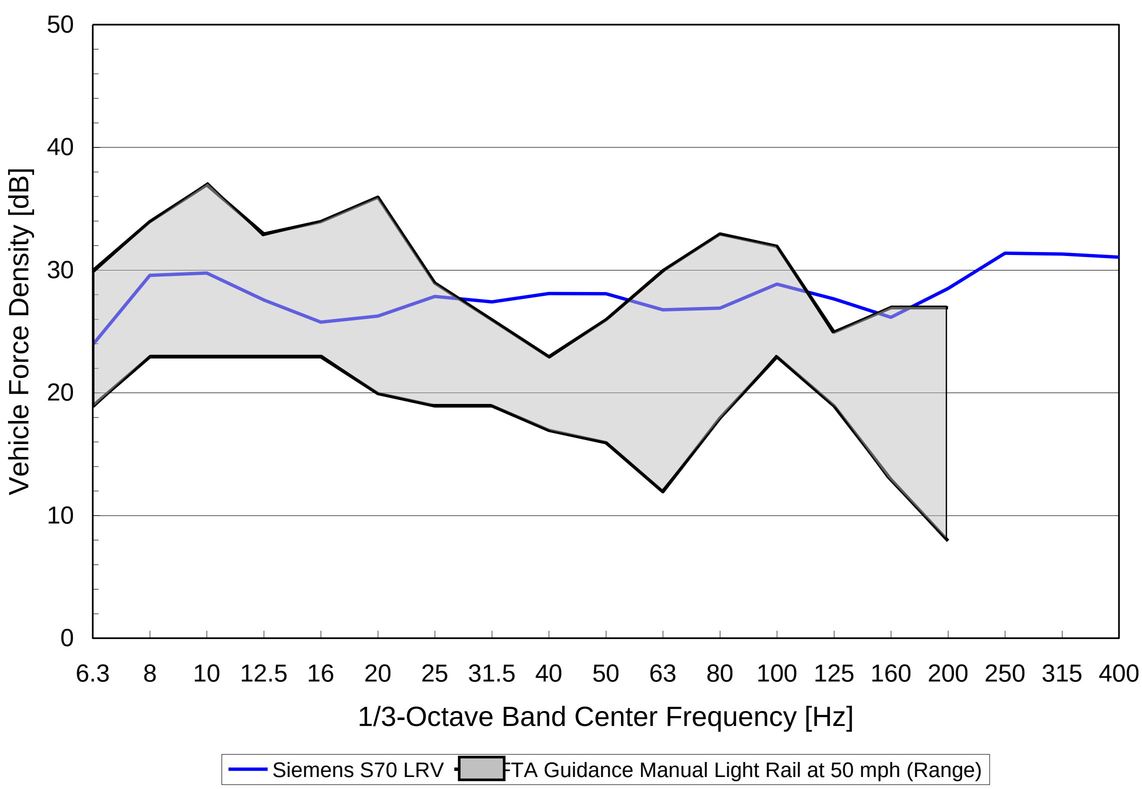
5.5.2 Outdoor-to-Indoor Building Coupling Results

Outdoor-to-indoor transfer mobility measurements of Duke Centennial Hall were conducted to quantify the attenuation of the building structure, or building coupling, to the ground floor and to an inertia block on the ground floor. These results are shown in Figure 8 in Appendix B. These measurements show that the building provides significant vibration attenuation (10 VdB or more) at frequencies below 50 Hz, a natural frequency is exhibited of the inertia block near 80 Hz, and then significant attenuation occurs at frequencies 250 Hz and above. The measurements on the slab floor also show a resonance at 80 Hz which may have been a result of measuring close to the inertia block.

5.5.3 Vibration Levels of LYNX Blue Line Trains (Force Density)

The force density of the Siemens S70 LRV was calculated based on maximum pass by vibration and LSTM measurements conducted at Remount Road on the existing South Corridor. The force density depends on train speed, consist and track condition (i.e. presence of special trackwork), but is independent of distance from the train. Force density has been calculated as described in Section 5.3.1. Figure 9 shows the force density of the Siemens S70 LRV at 50 mph along with the typical range of force density level according to the FTA Guidance Manual. This figure shows that the Siemens S70 LRV is generally within the typical range of force density levels. The force density is slightly higher in the 40-Hz and 125-Hz frequency ranges.

Figure 9
Force Density of Siemens S70 LRV at 50 mph

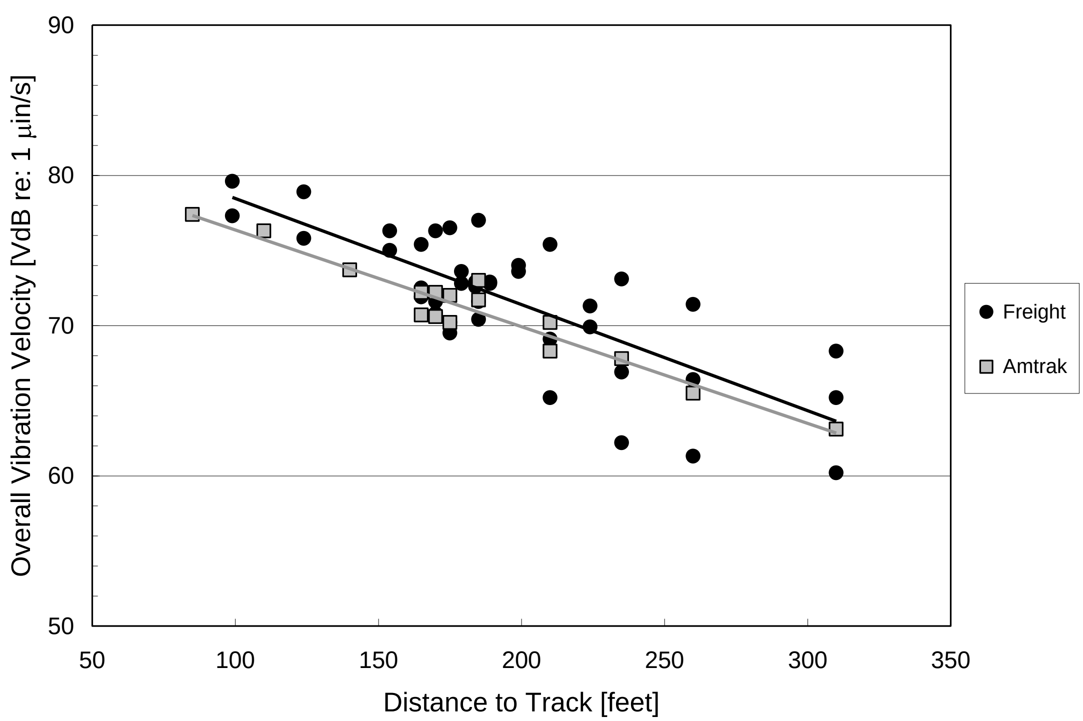


5.5.4 Vibration Levels of Amtrak and Freight Trains

Existing vibration levels of Amtrak trains and freight trains operating on the NCRR/NS mainline were measured at the North Park Mall. This measurement location is representative of existing vibration conditions at the Carolinas Medical Center – North Park and single-family homes at Prince Charles Street, St. Anne Place, Clintwood Drive, Leafmore Drive and Bearwood Drive. Measurements were conducted at various distances between 85 and 300 feet from the tracks. These measurement distances are representative of the proximity of the trains to sensitive receptors in this area, generally 80 to 150 feet from the existing NCRR/NS mainline tracks.

Amtrak trains traveled approximately 55 mph with one locomotive and three or four cars. Freight trains traveled between 35 and 55 mph with between one and five locomotives and between 29 and 75 cars. Figure 10 shows the overall vibration levels as a function of distance measured for both Amtrak and freight trains. This figure shows that vibration levels from Amtrak trains range from 77 VdB at a distance of 85 feet from the tracks to 63 VdB at a distance of 310 feet from the tracks. Since the freight trains were operating at a range of speeds, the vibration levels cover a greater range at any particular distance compared to the Amtrak trains. Generally, vibration levels from the freight trains range from 77 to 80 VdB at 100 feet and 60 to 68 VdB at 310 feet. Appendix C presents representative spectra for a freight train pass by and an Amtrak train pass by at distances of 85 to 225 feet. The vibration spectra show that Amtrak trains generate the most significant vibration in the 12.5-Hz to 25-Hz frequency range and freight trains generate the most significant vibration in the 5-Hz to 12.5-Hz frequency range.

Figure 10
Overall vibration level versus distance for existing Amtrak and freight trains



5.5.5 Ambient Vibration Levels near Sensitive Equipment at UNC Charlotte

Vibration measurements of the ambient conditions on the floor slab near sensitive equipment at the UNC Charlotte CRI were conducted to document existing conditions. The sources of ambient vibration at these locations include pedestrian footfalls, rotating machinery such as fans and pumps, elevators, rolling carts and nearby vehicular traffic on North Tryon Street/US-29 and the roads within the UNC Charlotte campus.

Figure 11 shows the ambient vibration spectra measured at UNC Charlotte CRI – Duke Hall at the metrology lab on the ground floor (off of inertia block) and the general VC curves. The median ambient vibration levels in all three directions (vertical and two orthogonal horizontal directions) are shown in the figures with solid red, green and blue lines. The typical range of vibration levels in each direction are depicted on the figure (dashed lines) with L10 and L90 spectral statistics. The L10 vibration spectrum is the vibration level in each 1/3-octave band that is only exceeded ten percent of the time. The L90 vibration spectrum is the vibration level in each 1/3-octave band that is exceeded 90 percent of the time. Therefore, the L10 and L90 spectra show the higher and lower ambient vibration levels present, respectively. Appendix D includes ambient vibration spectra measured at all vibration-sensitive locations.

A summary of ambient vibration measurement results is provided in Table 13. This table shows that existing ambient vibration conditions at UNC Charlotte CRI typically meet the VC-E criterion at ground floor receptors and meet the VC-B criterion at upper floor receptors. The vertical vibration levels are typically higher than the horizontal vibration levels.

Figure 11
Ambient vibration spectra at CRI - Duke Hall Metrology Lab

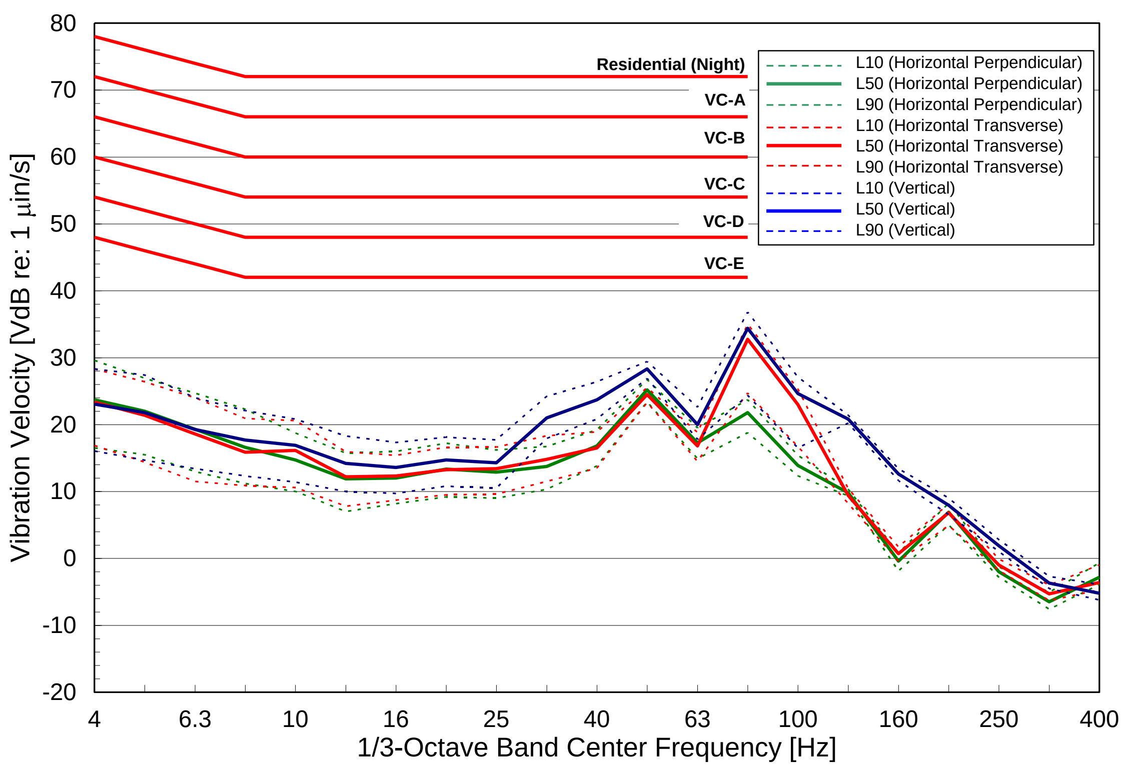


Table 13
Ambient Vibration Measurement Results

Measurement Location	Vibration-Sensitive Equipment	Vertical L10 Vibration Level (VdB)	Horizontal Perpendicular L10 Vibration Level (VdB)	Horizontal Transverse L10 Vibration Level (VdB)	Existing Vibration Levels Meet Vibration Criterion
Duke Centennial Hall Room 240 (2nd floor)	Scanning electron microscope	61.1	39.4	38.2	VC-B
Duke Centennial Hall Room 138C (ground floor on slab)	(Metrology Lab) Atomic force microscope, diamond machining center	36.8	29.6	35	VC-E
Duke Centennial Hall Room 138C (ground floor on inertia block)	(Metrology Lab) Atomic force microscope, diamond machining center	32.7	40.4	37.8	VC-E
Bioinformatics Room 332A (3rd floor)	DNA microarray	56.1	41.5	43.0	VC-B
Grigg Hall Room 239 (2nd floor)	Six-axis alignment system	64.1	49.8	45.6	VC-A
Grigg Hall Room 137 (ground floor)	Atomic force microscope	40.8	26.6	25.7	VC-E
Grigg Hall Room 153 (ground floor)	E-beam lithography	41.2	29.2	28.7	VC-E
Grigg Hall Room 152 (ground floor)	Scanning electron microscope	44.2	29.2	34.0	VC-D
Grigg Hall Room 371 (3rd floor)	(Clean room) General lithography equipment, mask aligner system	57.4	52.8	50.1	VC-B

6.0 NOISE AND VIBRATION IMPACT ASSESSMENT

This section presents the principal assumptions used in projecting noise and vibration from the proposed project and the results from the noise and vibration impact assessment. Noise and vibration impact has been assessed for long-term transit operations and short-term construction activities. Potential impact from transit operations has been assessed for the future no-build and locally-preferred alternative.

6.1 Analysis Assumptions

1. The noise and vibration impact assessment has been conducted based on the project layout approved for development of 65% design and the FEIS dated March 21, 2011 including the following more recent modifications to proposed alignment:
   - Northern terminus at UNC Charlotte
   - Storage tracks and a small dispatch building at the proposed VLMF site
   - Roadway improvements in the “weave” portion of the alignment

2. The proposed LYNX BLE trains would operate according to the following schedule:
- Weekday peak-period service (i.e. 6:30 a.m. to 9:30 a.m. and 4:00 p.m. to 7:00 p.m.) would be every 7.5 minutes (two-car trains) for initial operations and every ten minutes (three-car trains) by the design year 2035.
- Weekday off-peak service would be two-car trains every 15 minutes during the early morning, mid-day, and evening periods (i.e. 5:00 a.m. to 6:30 a.m. and 9:30 a.m. to 4:00 p.m.) and 20 minutes during the evening/night period (i.e. 7:00 p.m. to 1:00 a.m.)

It should be noted that potential noise and vibration impact were also assessed for two-car, six-minute train operations during peak-period. Noise and vibration conditions are very similar to those for three-car trains causing no difference in potential impact or mitigation.

3. The train speed has been determined based on the following operating assumptions:
- Acceleration and deceleration rate of 1.5 mphps (miles per hour per second)
- Speed is restricted to 15 mph between 7th Street and 9th Street
- Speed restrictions within the alignment may occur at 25, 35, 45 or 55 mph
- Maximum operating speed is 45 mph on North Tryon Street/US-29 and 55 mph elsewhere

4. The use of audible warning devices on the LYNX BLE is assumed to be consistent with the existing use on the South Corridor. Light rail vehicle operators sound the low horn through gated grade-crossings outside of Center City Charlotte and sound the bells in and out of stations. It is assumed that bells will be used through gated grade-crossings at 7th Street, 8th Street, 9th Street and the future 10th Street. At all other gated grade-crossings north of Center City Charlotte, the low horn will be sounded. All gated grade-crossings have crossing bells that sound for approximately 50 seconds as the gates are lowered while the train is approaching, during its pass by and while the gates are being raised.

The following grade-crossings outside of Center City Charlotte are assumed to be gated:
- 12th Street
- 16th Street
- Dispatch Facility Entrance
- Old Concord Road Station Park-and-Ride Access Road
- Orr Road
- Arrowhead Drive
- Owen Boulevard
- Tom Hunter Road
- Orchard Trace Lane
- University City Station Park-and-Ride Entrance
- Shopping Center Drive
- McCullough Drive
- Ken Hoffman Drive
- J.M. Keynes Drive
- JW Clay Boulevard
- UNC Charlotte Entrance

5. There proposed project includes the following TPSS along the corridor:
- TPSS 11 (existing) south of the alignment between 9th and 10th Street.
- TPSS 12 approximately 100 feet north of the proposed 25th Street Station
- TPSS 13 north of the alignment north of Craighead Road

- TPSS 14 approximately 50 feet southwest of Carolinas Medical Center – Northpark
- TPSS 15 just south of Heathway Drive
- TPSS 16 approximately 140 feet from Intown Suites at 110 Rocky River Road
- TPSS 17 in the median of North Tryon Street/US-29 just south of W.T. Harris Boulevard
- TPSS 18 approximately 50 feet north of the proposed UNC Charlotte Station

6. The proposed project includes the shifting of traffic lanes on North Tryon Street/US-29. to accommodate light rail in the median. The typical North Tryon Street/US_29 cross section includes two lanes in each direction, plus turn lanes at intersections. In addition, a third lane for right/through movements is being added in both directions in the "weave" portion of the project. The speed limit will be modified for the future Build condition from 45 mph to 35 mph.

7. The proposed project includes four park-and-ride facilities. The noise analysis conservatively assumes that the entire capacity of each park-and-ride will enter and leave the facilities throughout the day with 50% of the capacity entering and leaving during the AM and PM peak hours. The following outlines the park-and-ride capacities.

- Sugar Creek Station – 665 parking spaces in two surface lots
- Old Concord Road Station – 330 parking spaces in one surface lot
- University City Blvd. Station – 1,485 parking spaces in a parking deck
- JW Clay Blvd. Station– 690 parking spaces in a parking deck

8. The proposed project includes modifications to the existing NCRR/NS mainline and yard lead tracks. The existing yard lead track which extends north to 36th Street and then merges into the northbound mainline track would be shortened approximately 1100 feet and merge into the northbound mainline near 33rd Street. The NCRR/NS mainline tracks will be shifted up to 80 feet north between 30th Street and just north of Craighead Road. The NCRR/NS mainline tracks continue, unmodified, next to the proposed LYNX BLE until the BLE leaves the NCRR ROW before the proposed Old Concord Station where the LYNX BLE would transition to North Tryon Street/US-29.

9. The proposed project assessed for the Draft EIS included a Vehicle Light Maintenance Facility (VLMF). The current alignment analyzed in this study eliminates the VLMF and includes a storage yard and dispatch facility located north of North Brevard Street between East 23rd Street and East 25th Street. There would be additional noise due to the non-revenue pull-in and pull-out movements on the north side of the yard; however, the closest sensitive land is over 1200 feet from this facility and therefore noise from the facility does not contribute significantly to future noise conditions.

10. The primary construction activities for the proposed project include at-grade track, station, and track, bridge or underpass construction including impact pile driving, sonic pile driving or auger drilling and road construction including clearing, foundation, paving and finishing. The following outlines assumptions for the key noise-generating equipment that may be used for each type of construction:

- <u>At-grade Track</u>: Air compressor, backhoe or bulldozer, grader or tie inserter, dump truck
- <u>Station or Parking Lot</u>: Air compressor, backhoe or bulldozer, concrete mixer, dump truck
- <u>Elevated Guideway, Retaining Wall, Bridge, Underpass or Parking Deck Construction</u>: Air compressor, backhoe or bulldozer, crane, grader or tie inserter, dump truck, concrete mixer and an impact pile driver, sonic pile driver or auger driller.
- <u>Road (Clearing)</u>: Air compressor, backhoe, bulldozer, hoe ram, jackhammer, scraper and dump truck.

- Road (Foundation): Air compressor, concrete mixer, bulldozer, grader, pneumatic tool, roller and dump truck.
- Road (Paving): Air compressor, concrete mixer, paver and dump truck.
- Road (Finishing): Air compressor, backhoe, concrete mixer, bulldozer, grader, jackhammer, roller and dump truck.

The following outlines assumptions for which vibration-generating equipment may be used for each type of construction:

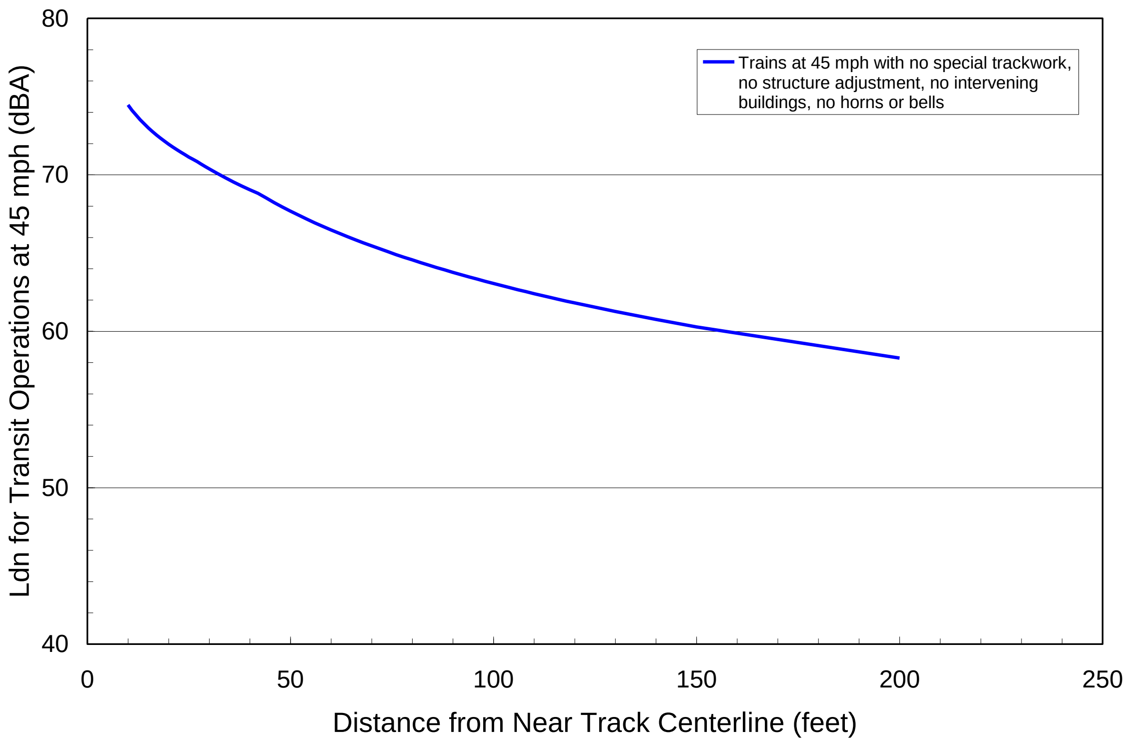
- At-grade Track, Station or Parking Lot Construction: Large bulldozer or backhoe, small bulldozer and a vibratory roller for soil compaction.
- Elevated Guideway, Retaining Wall, Bridge, Underpass or Parking Deck Construction: Large bulldozer or backhoe, small bull dozer, vibratory roller for soil compaction and impact pile driving, sonic pile driving or auger drilling for sheet piling and/or pier construction.
- Road: Large bulldozer or backhoe and hoe ram.

6.2 Noise Projections from Transit Operations

Future noise levels from the proposed LYNX BLE have been projected according to the methodology described in the FTA guidance manual including project-specific reference noise measurements of the Siemens S70 LRV, audible warning devices and a traction power substation. Noise projections take into account the operations of the proposed light rail including the speed of the trains, headways, train consists, the use of audible warning devices and the track design including special trackwork (crossovers and turnouts) and curvature. Noise projections include adjustments for elevated guideways, terrain, building rows and other features that may affect sound propagation conditions. Other sources included in the projections are noise from park and ride facilities, traction power sub stations and noise from the proposed light rail maintenance facility.

Figure 12 shows the projected Ldn from transit operations at 45 mph as a function of distance to the near track centerline. These projections assume there is no special trackwork, no structure adjustments (i.e. elevated guideway), no intervening building rows, no horns or bells, no wheel-squeal and flat soft ground. This figure shows that transit operations generate an Ldn of 75 dBA 10 feet from the near track centerline and an Ldn of 58 dBA at 200 feet.

Figure 12
Noise projections from transit operations at 45 mph



When operating on tight-radius curves, light rail trains have the potential to generate wheel squeal. Wheel squeal occurs from the lateral stick-slip movement of the wheels across the rail head on curves. Wheel squeal is a very tonal noise that can be highly annoying. Typically, the potential for wheel squeal only occurs on curves that are up to 100 times the wheel base of the LRV or less. The wheel base of the Siemens S70 LRV is 6.2 feet for powered trucks and 5.9 feet for the center truck.[1] Therefore, based on measurements of LRV's operating on tight radius curves, it is assumed that the CATS LYNX BLE LRV will generate a SEL of 92 dBA at a distance of 50 feet from the track for all curves with a radius of 620 feet or less. This SEL is not a function of train speed as is the general rolling noise which typically varies with train speed and is not the controlling factor when wheel squeal is present.

Noise from TPSS's has also been included in the noise projections (locations are detailed in Section 6.1). The TPSS's on the proposed alignment are enclosed. There is very minimal noise from the transformers inside the enclosure. The dominant noise sources of the traction power substation are fans on two sides of the enclosure used to cool the interior space. Although the maximum noise from the TPSS is relatively low (57 dBA at 50 feet), they run relatively constantly so there is the potential for noise impact at close distances.

Noise from park–and-ride facilities has also been included in the projections (locations are detailed in Section 6.1). Based on FTA guidelines, park-and-ride stations are assumed to generate a Ldn of 71.8 dBA at a distance of 50 feet from the geometric center of the park and

[1] Siemens Transportation Systems, Inc. specifications for Charlotte S70 Light Rail Vehicle, 2007.

ride station for an activity of 1000 cars and 12 buses per hour. Park-and-ride noise is assumed to be a stationary source which attenuates with distance at a rate of six decibels per distance doubling.

At some locations along the proposed corridor, there would be roadway improvements associated with the project such as shifting or increasing lanes of travel. Future noise conditions under these circumstances include these changes to traffic noise (only from roadway improvements directly associated with the project) as well as noise from transit operations. Under these circumstances, noise impact is assessed according to the increase in future noise conditions as shown in Figure 5. Traffic noise has been predicted according to FTA guidelines which include a reference SEL of 74 dBA at 50 feet for cars and 82 dBA for buses and trucks. The relationship of speed to sound level, i.e. the speed coefficient, is 30 log(speed) for cars and 15 log(speed) for buses and trucks. Traffic noise has been modeled as a line source with a drop off in sound level of 4.5 decibels per distance doubling.

6.3 Vibration Projections from Transit Operations

Future vibration levels from LYNX BLE trains along the proposed alignment are projected based on the reference vibration levels of Blue Line trains (force density), propagation characteristics of the soil, the proximity of sensitive receptors to the proposed alignment, the speed of the Blue Line trains, the presence of any special trackwork (i.e. crossovers or turnouts) and building coupling factors. Vibration levels from the trains are computed according to the following equation:

$$Lv = FD + LSTM + \textit{Structural Coupling} + \textit{Special Trackwork}$$

Where, *FD* is the force density of the Blue Line trains at the proposed speed, *LSTM* is the line source transfer mobility from the tracks to the sensitive receptor, *Structural Coupling* accounts for the interaction of ground-vibration to the building structure and/or the coupling effect from elevated track structures and *Special Trackwork* takes into account increases in vibration due to the trackform (i.e. crossovers and turnouts).

Figure 13 shows the overall vibration levels from 3-car train operations at 45 mph projected at all measurement locations as a function of distance. These projections do not include any adjustments for structural coupling or special trackwork. This figure shows that vibration levels span a range of approximately 20 decibels across all sites depending on soil propagation conditions. The most efficient soil propagation conditions exist at Site V-6, Kirk Farm Fields and the least efficient propagation conditions exist at Site V-1, East 11th Street and North Brevard Street. Generally, the distances to an overall vibration level of 72 VdB range from 20 to 80 feet.

Potential vibration impact is assessed based on the vibration spectrum at sensitive receptors where the levels in each 1/3-octave band between four and 80 Hz are compared to the criteria. Figure 14 shows vibration spectra from 3-car LYNX BLE trains at 45 mph projected at a range of distances from the near track centerline for the UNC Charlotte CRI buildings. These projections include adjustments for building coupling and do not include adjustments for special trackwork. This figure shows how vibration levels are attenuated at greater distances from the alignment. Vibration levels at 25 feet exceed the residential nighttime criterion of 72 VdB inside the ground floor of the building; however, at distances of 160 feet or further from the alignment, vibrations from Blue Line trains would be below the VC-E criterion on the slab floor inside the buildings.

Figure 13
Overall vibration projections at all sites vs. distance

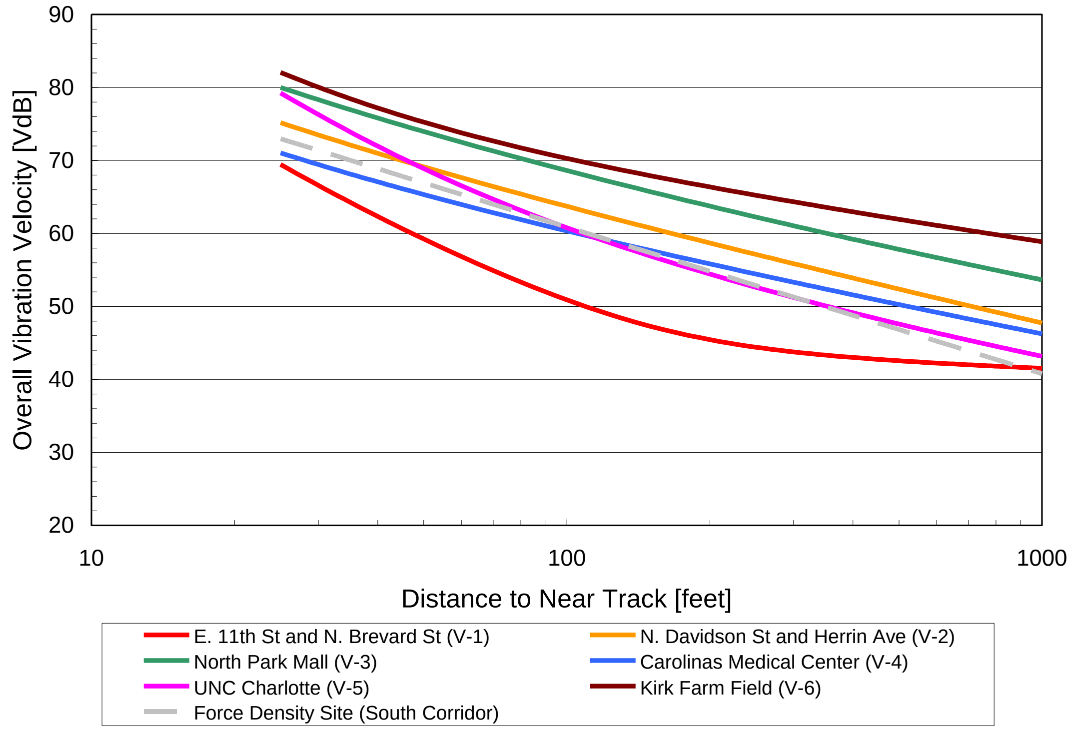
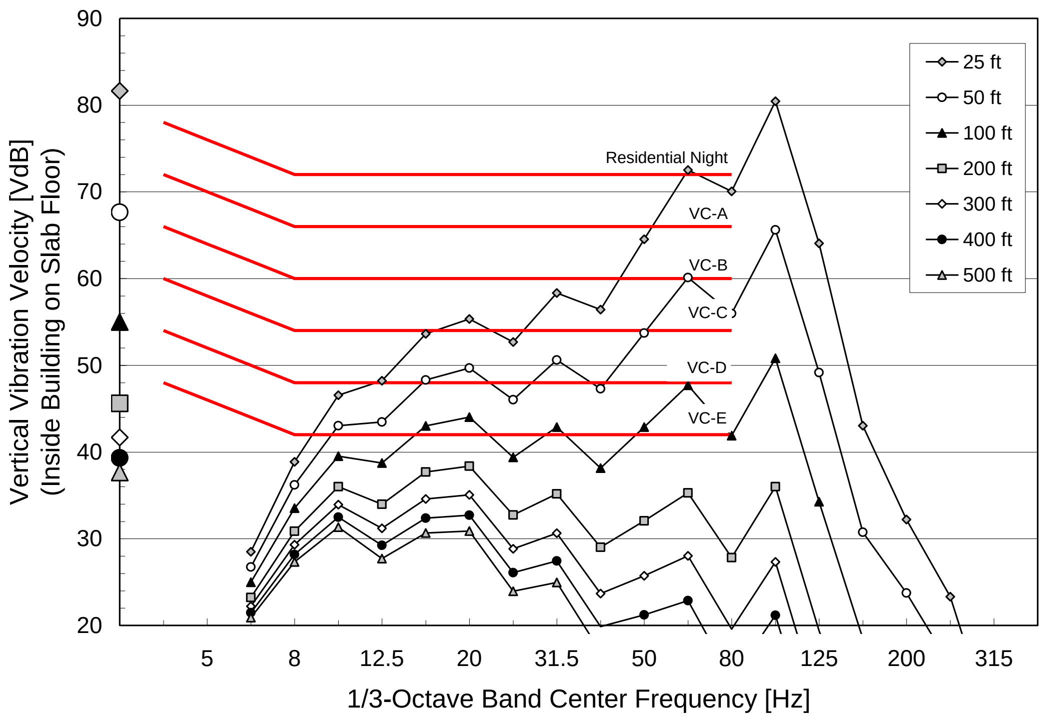


Figure 14
Vibration projections at various distances at UNC Charlotte CRI



6.4 Noise Projections from Construction Activities

Projecting construction noise requires a construction scenario of the equipment likely to be used and the average utilization factors or duty cycles (i.e. the percentage of time during operating hours that the equipment operates under full power during each phase). The reference sound levels at 50 feet and utilization factors are based on the Federal Highway Administration Construction Noise Handbook.[2] Using typical sound propagation characteristics, it is then possible to estimate Leq at various distances from the construction site. Table 14 presents noise projections at 50 feet for at-grade track, station or parking lot construction and elevated guideway, retaining wall, bridge, underpass or parking deck construction which may include impact pile driving, sonic pile driving or auger drilling for piers and/or retaining walls. Table 15 presents noise projections at 50 feet for road construction. The noise impact assessment for a construction site is based on:

- an estimate of the type of equipment that will be used during each phase of the construction and the average daily duty cycle for each category of equipment,
- typical noise emission levels for each category of equipment
- noise attenuation as a function of distance from the construction site.

Based on the construction scenarios shown in Table 14 and Table 15, the distances to potential noise impact can be calculated. These distances, shown in Table 16 and Table 17 do not include any noise reduction from intervening objects (i.e. terrain or buildings) or reduction from mitigation measures.

Table 14
Construction noise projections for track construction

Equipment	Maximum Sound Level at 50 ft (dBA)	Utilization Factor	8-hour Leq (dBA)			
			At-Grade Track, Station or Parking Lot Construction	Elevated Guideway, Retaining Wall, Bridge, Underpass or Parking Deck Construction (with Drilling)	Elevated Guideway, Retaining Wall, Bridge, Underpass or Parking Deck Construction (with Impact Driving)	Elevated Guideway, Retaining Wall, Bridge, Underpass or Parking Deck Construction (with Sonic Driving)
Air Compressor	80	40%	76	76	76	76
Backhoe	80	40%	76	76	76	76
Crane	85	20%		78	78	78
Grader or Tie Inserter	85	40%	81[1]	81	81	81
Dump Truck	84	40%	80	80	80	80
Concrete Mixer	85	40%	81[2]	81	81	81
Auger Drilling	85	20%		78		
Pile Driving (Impact)	95	20%			88	
Pile Driving (Sonic)	95	20%				88
Total 8-hour Leq at 50 ft			**84.9**	**87.5**	**90.5**	**90.5**

[1] For at-grade track construction
[2] For station and parking lot construction

[2] Knauer, Harvey, et. al, "FHWA Highway Construction Noise Handbook", Report prepared for the U.S. Department of Transportation, Federal Highway Administration, Report FHWA-HEP-06-016, August 2006.

Table 15
Construction noise projections for road construction

Equipment	Maximum Sound Level at 50 ft (dBA)	Utilization Factor	8-hour Leq (dBA)			
			Clearing	Foundation	Paving	Finishing
Air Compressor	80	40%	76	76	76	76
Backhoe	80	40%	76			76
Concrete Mixer	85	40%		81	81	81
Bulldozer	85	40%	81	81		81
Grader	85	40%		81		81
Hoe Ram	90	20%	83			
Jackhammer	85	20%	78			78
Paver	95	50%			82	
Pneumatic Tool	85	50%		82		
Roller	85	20%		78		78
Scraper	85	40%	81			
Dump Truck	84	40%	80	80	80	80
Total 8-hour Leq at 50 ft			**88.4**	**88.7**	**86.3**	**88.4**

Table 16
Distances to potential track construction noise impact

Land Use	Time of Day[1]	Noise Impact Criterion (8-hour Leq, dBA)	Distance to Potential Construction Noise Impact Prior to Mitigation (feet)			
			At-Grade Track, Station or Parking Lot Construction	Elevated Guideway, Retaining Wall, Bridge, Underpass or Parking Deck Construction (with Drilling)	Elevated Guideway, Retaining Wall, Bridge, Underpass or Parking Deck Construction (with Impact Driving)	Elevated Guideway, Retaining Wall, Bridge, Underpass or Parking Deck Construction (with Sonic Driving)
Residential	Daytime	80	78	100	132	132
	Nighttime	70[2]	197[2]	250[2]	331[2]	331[2]
Commercial	Daytime	85	49	63	83	83
	Nighttime	85	49	63	83	83
Industrial	Daytime	90	31	40	52	52
	Nighttime	90	31	40	52	52

[1] Daytime is defined as 7am to 10pm, Nighttime is defined as 10pm to 7am.
[2] City of Charlotte Noise Ordinance does not allow construction machinery to be used between 9:00pm and 7:00am in any part of the city zoned for residential use. Nighttime construction restrictions do not apply to hotels and motels, so potential impact is assessed for nighttime residential land use.

Table 17
Distances to potential road construction noise impact

Land Use	Time of Day[1]	Noise Impact Criterion (8-hour Leq, dBA)	Distance to Potential Construction Noise Impact Prior to Mitigation (feet)			
			Clearing	Foundation	Paving	Finishing
Residential	Daytime	80	109	111	89	108
	Nighttime	70[2]	273[2]	280[2]	224[2]	271[2]
Commercial	Daytime	85	69	70	56	68
	Nighttime	85	69	70	56	68
Industrial	Daytime	90	43	44	36	43
	Nighttime	90	43	44	36	43

[1] Daytime is defined as 7am to 10pm, Nighttime is defined as 10pm to 7am.
[2] City of Charlotte Noise Ordinance does not allow construction machinery to be used between 9:00pm and 7:00am in any part of the city zoned for residential use. Nighttime construction restrictions do not apply to hotels and motels, so potential impact is assessed for nighttime residential land use.

6.5 Vibration Projections from Construction Activities

Construction vibration, similar to noise, is highly dependent on the specific equipment and methods employed. Construction equipment that may generate significant vibration includes dump trucks, concrete mixers, back hoes or large bulldozers, auger drilling, impact pile driving, sonic pile driving and vibratory rollers. The primary concern for vibration from construction activities is the potential for structural damage to buildings. The methodology for assessing construction vibration impact is based on using reference vibration levels at a distance of 25 feet and generalized vibration propagation conditions of the soil to predict vibration levels at sensitive receptors. Projections do not account for any building coupling factor.

Construction vibration levels at buildings are calculated as follows:

$$Lv(D) = Lv(25\text{ feet}) - 30 \cdot \text{Log}(\text{Distance}/25\text{ feet})$$

Vibration projections for potential structural damage at all buildings near construction activities are presented in Appendix I and summarized previously in Table 2. Vibration projections for potential impact to sensitive equipment at UNC Charlotte CRI are presented in Appendix J and summarized previously in Table 3. Table 18 shows the reference vibration level for each piece of construction equipment and the distance to potential structural damage for each building construction type.

Table 18
Distances to potential construction vibration impact

Equipment	Vibration Level at 25 ft (VdB)	Distance to Potential Structural Damage (feet)			
		Reinforced Concrete, Steel or Timber Building (102 VdB)	Engineered-concrete and Masonry (98 VdB)	Non-engineered Timber and Masonry (94 VdB)	Buildings Extremely Susceptible to Vibration (90 VdB)
Large Bulldozer/Backhoe	86	7	10	14	18
Small Bulldozer	58	1	1	2	2
Dump Truck	86	7	10	14	18
Concrete Mixer	86	7	10	14	18
Auger Drilling	87	8	11	15	20
Hoe Ram	87	8	11	15	20
Pile Driving (Impact)	104	29	40	54	73
Pile Driving (Sonic)	93	13	17	23	31
Vibratory Roller	94	14	18	25	34

The construction vibration assessment projections show that:

- Potential structural damage may occur within seven to 18 feet of buildings from large bulldozers, dump trucks, concrete mixers and hoe rams.
- Potential structural damage may occur within one to two feet of building from small bulldozers.
- Potential structural damage may occur within eight to 20 feet of buildings from auger drilling.
- Potential structural damage may occur within 29 to 73 feet from impact pile driving and within 13 to 31 feet from sonic pile driving.
- Potential structural damage may occur within 14 to 34 feet of buildings from vibratory roller compaction.

6.6 Transit Noise Impact Assessment

6.6.1 Noise Impact Assessment for No-build Alternative

The no-build alternative would not introduce a new noise source into the environment and there would not be any potential noise impact.

6.6.2 Noise Impact Assessment for Locally Preferred Alternative

Noise impact has been assessed for the locally-preferred alternative using the FTA detailed noise impact assessment methodology. The proposed LYNX BLE would introduce a new noise source into the environment which may cause impact to sensitive receptors. Table 19 summarizes the receptors that may be exposed to potential noise impact prior to mitigation including the receptor location, side of tracks, distance to near track centerline, speed of train, existing noise level, moderate and severe impact criteria based on project noise, project noise levels, future noise levels (which include project noise and existing noise sources), and the total number of buildings that may be exposed to impact. Prior to mitigation, potential severe noise impact would occur at three sensitive receptors including a single-family residence at 328

Parkwood Avenue (Appendix F, Figure 3), the UNC Charlotte Laurel Residence Hall and the UNC Charlotte Spruce Residence Hall (Appendix F, Figure 6) and moderate noise impact would occur at seven sensitive receptors including two multi-family buildings at 311 East 12th Street (Alpha Mill) (Appendix F, Figure 2), single-family residences at 402 East 19th Street (Appendix F, Figure 3), 352, 358 and 364 Leafmore Drive (Appendix F, Figure 4) and the Marriott Residence Inn Hotel at 8503 North Tryon Street/US-29 (Appendix F, Figure 5).

Table 19
Potential noise impact prior to mitigation

Noise Sensitive Receptor Location	Side of Tracks	Distance to Near Track Centerline (feet)	Speed of LRV (mph)	Existing Noise Level (Ldn)	Project Noise Impact Criteria (Ldn)		Project Noise Level (Ldn)	Future Noise Level (Ldn)	Total Number of Impacts (Buildings)	
					Mod.	Sev.			Mod.	Sev.
311 East 12th Street (Alpha Mill Apartments)	East	90	45	71.0	65.0	70.2	67.0	72.5	2	0
328 Parkwood Avenue (single-family residence)	East	100	30	69.0	63.6	68.8	72.3[1]	74.0	0	1
402 East 19th Street (single-family residence)	East	150	25	69.0	63.6	68.8	68.2[1]	71.6	1	0
358 Leafmore Drive (single-family residences)	West	65	55	70.4	64.7	69.8	67.7	72.3	1	0
352 and 364 Leafmore Drive (single-family residences)	West	80	55	69.8	64.1	69.3	66.3	71.4	2	0
8503 North Tryon Street/US-29 (hotel)	West	90	45	71.4	65.0	71.4	66.9[3]	72.7	1	0
UNC Charlotte Spruce Residence Hall	South	250	15[2]	62.1	59.0	64.5	72.6[1]	73.0	0	1
UNC Charlotte Laurel Residence Hall	South	220	15[2]	62.1	59.0	64.5	67.7[1]	68.8	0	1
Total Noise Impacts for Category 2 Land Use (Residential)									7	3
Total Noise Impacts for Category 3 Land Use (Institutional)									0	0
Total Noise Impacts for Category 3 Land Use (Park)									0	0

[1] Projections include contribution from wheel squeal on tight-radius curve.
[2] Receptor is near station. Projections include use of bells, acceleration and deceleration into station.
[3] Projections include grade-crossing bells and train horn.

Noise impact at 311 East 12th Street (Alpha Mill Apartments) is due primarily to the horn sounding through the gated at-grade crossing at 12th Street. Noise impact near Parkwood Station is due primarily to the potential for wheel squeal on tight-radius curves. Noise impact near UNC Charlotte Station is due primarily to increased noise from a double-crossover and the potential for wheel squeal on a tight-radius curve. Noise impact near Leafmore Drive is due to the close proximity of sensitive receptors to the proposed alignment and the speed of the trains. Noise impact at 8503 North Tryon Street/US-29 is due primarily to the proximity to the proposed crossing bells at Ken Hoffman Drive gated grade-crossing and the horn sounding of the train.

The following are a few notable receptors that would not be exposed to noise impact prior to mitigation. Potential noise impact was identified at some of these receptors in the Draft EIS. Typically, if impact was identified in the Draft EIS it was only one or two decibels above the moderate impact criteria. The detailed noise analysis conducted in this study has determined the following results:

- Pine Mobile Home Park would not be exposed to potential noise impact prior to mitigation. These receptors are set back over 200 feet from the proposed alignment and existing noise levels are relatively high, with a Ldn of 62 dBA, due to existing traffic noise on North Tryon Street/US-29.
- A single-family residence at 332 St. Anne Place, approximately 45 feet from the proposed alignment, would not be exposed to noise impact. The project would include a retaining wall in this area that would provide significant noise reduction to the Blue Line trains. With this acoustic shielding, future project noise levels would be below the moderate impact criterion.
- Noise impact would not occur at the Carolinas Medical Center – University prior to mitigation. This receptor is set back approximately 240 feet from the proposed alignment.
- Potential noise impact would not occur at the Intown Suites Hotel at 110 West Rocky River Road in the “weave” portion of the proposed alignment. This portion of the project includes roadway improvements and a proposed TPSS approximately 140 feet from the property. Since future build conditions include a decrease in traffic speed (from 45 mph to 35 mph), future noise contributions from traffic are projected to be approximately three decibels lower with the proposed project. The reduced speed more than offsets the increase in traffic volumes and decreased distances to the roadway.

A summary of total residential, institutional and park receptors exposed to noise impact prior to mitigation is presented in Table 20. Appendix G includes noise projections at all receptors prior to mitigation.

Table 20
Summary of potential noise impact prior to mitigation

Residential Buildings Impacted		Institutional Buildings and Parks Impacted	
Moderate	Severe	Moderate	Severe
6	3	0	0

6.7 Construction Noise Impact Assessment

Potential construction noise impact has been assessed at residential, commercial and industrial locations near the proposed alignment. Construction activities include at-grade track, station, parking lot, elevated guideway, retaining wall, bridge, underpass and parking deck construction and road construction. Based on the distances to potential impact projected in Table 16 and Table 17, construction noise impact may occur at 19 residential properties, nine hotels or motels, 12 commercial properties and five industrial properties prior to mitigation as shown in Table 21 and in Appendix F, Figures 8a and 8b.

Table 21
Potential construction noise impact prior to mitigation

Receptor Number	Receptor Location	Land Use Type	Distance to Construction (feet)	Impact Criterion (8-hour Leq)	Construction Noise (8-hour Leq)	Type of Construction
1	301 East 7th Street	Commercial	22	85	94	At-grade Track
2	301 East 8th Street	Commercial	40	85	87	At-grade Track
3	301 East 9th Street	Commercial	45	85	86	At-grade Track
4	311 East 12th Street	Residential	80	80 (day)	82 to 85	Retaining Wall
5	430 East 36th Street	Industrial	35	90	91 to 94	Retaining Wall
6	407 East 36th Street	Industrial	30	90	93 to 96	Retaining Wall
7	3327 North Davidson Street	Industrial	30	90	91 to 94	Elevated Guideway
8	501 Patterson Street	Residential	80	80 (day)	82 to 85	Elevated Guideway
9	3440 North Davidson Street	Residential	115	80 (day)	78 to 81	Elevated Guideway
10	500 Herrin Avenue	Residential	100	80 (day)	80 to 83	Elevated Guideway
11	3510 North Davidson Street	Residential	100	80 (day)	80 to 83	Elevated Guideway
12	3528 North Davidson Street	Residential	110	80 (day)	79 to 82	Elevated Guideway
13	601 East Sugar Creek Road	Industrial	20	90	97 to 100	Retaining Wall
14	4300 Raleigh Street	Industrial	40	90	90 to 93	Retaining Wall
15	352 Leafmore Drive	Residential	65	80 (day)	82	At-grade Track
16	358 Leafmore Drive	Residential	65	80 (day)	82	At-grade Track
17	364 Leafmore Drive	Residential	65	80 (day)	82	At-grade Track
18	331 Barrymore Drive	Residential	120	80 (day)	78 to 81	Retaining Wall
19	332 St. Anne Place	Residential	45	80 (day)	89 to 92	Retaining Wall
20	341 Prince Charles Street	Residential	100	80 (day)	80 to 83	Retaining Wall
21	337 Prince Charles Street	Residential	120	80 (day)	80 to 83	Retaining Wall
22	333 Prince Charles Street	Residential	100	80 (day)	80 to 83	Retaining Wall
23	329 Prince Charles Street	Residential	100	80 (day)	80 to 83	Retaining Wall
24	325 Prince Charles Street	Residential	100	80 (day)	80 to 83	Retaining Wall
25	321 Prince Charles Street	Residential	100	80 (day)	80 to 83	Retaining Wall

Table 21 (continued)
Potential construction noise impact prior to mitigation

Receptor Number	Receptor Location	Land Use Type	Distance to Construction (feet)	Impact Criterion (8-hour Leq)	Construction Noise (8-hour Leq)	Type of Construction
26	317 Prince Charles Street	Residential	120	80 (day)	78 to 81	Retaining Wall
27	5500 Old Concord Road	Commercial	40	85	87	Parking Lot
28	5636 North Tryon Street/US-29	Commercial	70	85	84 to 87	Elevated Guideway
29	5655 North Tryon Street/US-29	Commercial	60	85	84 to 86	Road
30	5703 North Tryon Street/US-29	Commercial	60	85	84 to 86	Road
31	5732 North Tryon Street/US-29	Commercial	70	85	84 to 87	Elevated Guideway
32	5901 North Tryon Street/US-29	Residential	75	80 (day)	82 to 84	Road
33	5911 North Tryon Street/US-29	Hotel/Motel	70[2] 40[3]	80 (day) 70 (night)	81[2] 89 to 91[3]	At-grade Track Road
34	6001 North Tryon Street/US-29	Hotel/Motel	60[2] 40[3]	80 (day) 70 (night)	83[2] 89 to 91[3]	At-grade Track Road
35	6426 North Tryon Street/US-29	Hotel/Motel	110	80 (day) 70 (night)	78 to 80	Road
36	110 West Rocky River Road	Hotel/Motel	220	80 (day) 70 (night)	71 to 74	Elevated Guideway
37	7706 North Tryon Street/US-29	Hotel/Motel	140[2] 110[3]	80 (day) 70 (night)	76 to 79[2] 80 to 82[3]	Elevated Guideway and Road
38	8001 North Tryon Street/US-29	Commercial	50	85	86 to 88	Road
39	132 East McCullough Drive	Hotel/Motel	120	80 (day) 70 (night)	75	At-grade Track
40	8404 North Tryon Street/US-29	Commercial	70	85	83 to 85	Road
41	8419 North Tryon Street/US-29	Hotel/Motel	160	80 (day) 70 (night)	72	At-grade Track
42	8503 North Tryon Street/US-29	Hotel/Motel	90[2] 50[3]	80 (day) 70 (night)	81 to 84[2] 86 to 88[3]	Elevated Guideway and Road
43	8517 North Tryon Street/US-29	Hotel/Motel	80	80 (day) 70 (night)	81 to 83	Road
44	8926 J.M.Keynes Drive	Commercial	50	85	86 to 88	Road
45	9321 JW Clay Boulevard	Commercial	50	85	87 to 91	Parking Deck

[1] Nighttime construction restrictions do not apply to hotels and motels, so potential impact has been assessed for nighttime residential land use.
[2] For track construction.
[3] For road construction.

6.8 Transit Vibration Impact Assessment

6.8.1 Vibration Impact Assessment for No-build Alternative

The no-build alternative would not introduce a new vibration source into the environment and there would not be any potential vibration impact.

6.8.2 Vibration Impact Assessment for Locally-Preferred Alternative

Vibration impact has been assessed for all vibration-sensitive land use and vibration-sensitive equipment along the corridor. The applicable vibration criteria for FTA Category 2 (residences and places people sleep), Category 3 (schools and places of worship) and vibration-sensitive equipment were presented in Section 3.3. Future vibration levels have been projected at all sensitive receptors based on the methodology outlined in Section 6.3 which account for train speed, consist, presence of special trackwork, measurements of the vibration propagation conditions of the soil and coupling response of the buildings.

Existing Amtrak trains along the NCRR/NS mainline tracks between Bearwood Avenue and Eastway Drive generate overall vibration levels of 75 VdB at a distance of approximately 100 feet. Existing freight trains generate overall vibration levels of 75 VdB at a distance of 150 to 200 feet depending on the train speed. Since the project does not include any modifications to the NCRR/NS mainline track in this segment, vibration levels from Amtrak and freight operations would not change and there would not be vibration impact from these sources due to the LYNX BLE project.

Figure 15 shows vibration spectra projected inside the ground floor of the UNC Charlotte Bioinformatics building, Duke Centennial Hall, Grigg Hall and EPIC building (under construction) and CMC-University. Projections at UNC Charlotte are for trains at the closest point of approach to the buildings and do not include any increase due to special trackwork. CMC-University is approximately 240 feet from the closest point of the near track centerline and 500 feet from a double-crossover just south of the proposed JW Clay Blvd. Station. Projections at CMC-University are for the trains traveling over the double-crossover (which includes a ten decibel increase in vibration) since this location represents the highest vibration levels from the trains. This figure shows that vibration levels would be four decibels or more below the VC-E criterion at all receptor locations at UNC Charlotte and three decibels or more below the VC-D criterion at CMC-University.

Figure 15
Vibration projections inside UNC Charlotte CRI and CMC-University buildings

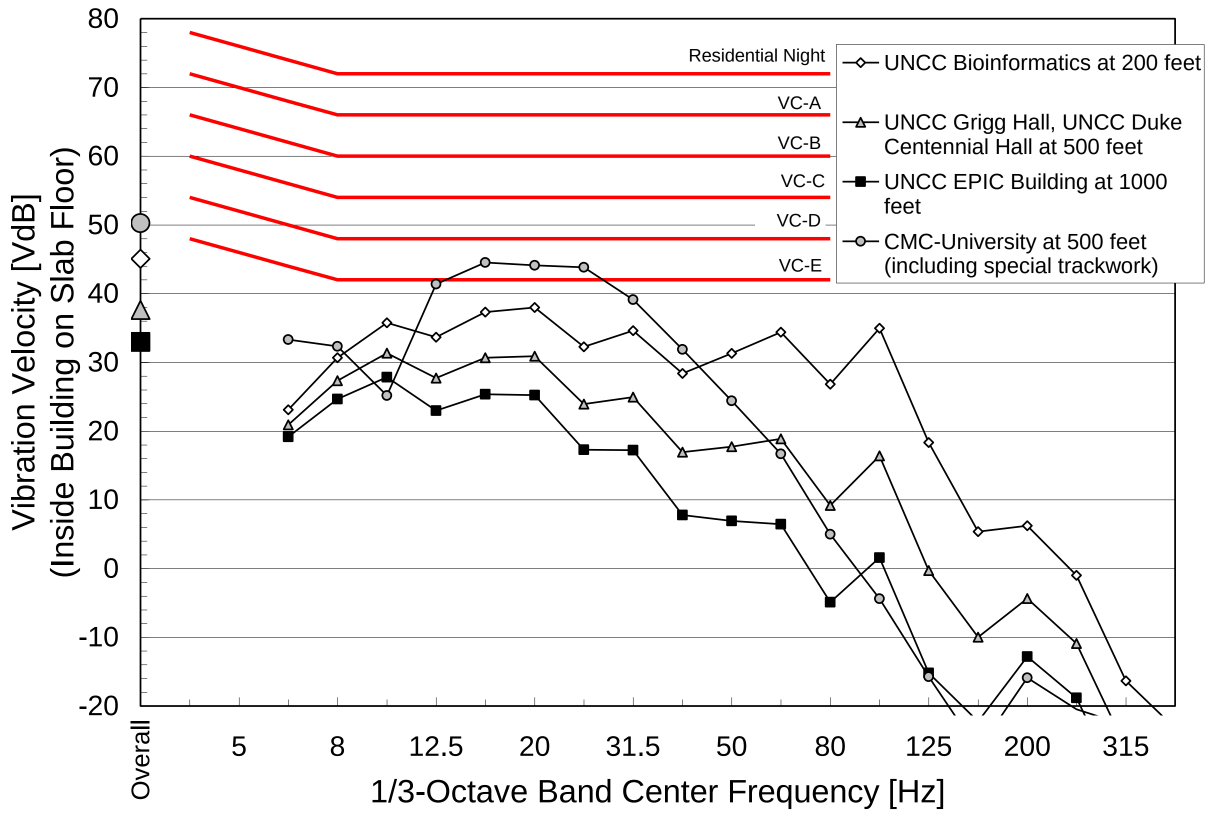


Table 22 presents the sensitive receptors along the proposed alignment that would be exposed to vibration impact prior to mitigation. This table includes the receptor location, distance to the near track centerline, the train speed, the maximum vibration velocity measured in any 1/3-octave band between four and 80 Hz and the total number of buildings impacted. A single-family residence at 332 St. Anne Place (Appendix F, Figure 7) is the only property along the proposed alignment that would potentially be impacted by vibration prior to mitigation.

Table 22
Potential vibration impact prior to mitigation

Vibration Sensitive Receptor Location	Side of Tracks	Distance to Near Track Centerline (feet)	Speed of LRV (mph)	Maximum Vibration Velocity in any 1/3-octave band from 4 to 80 Hz (VdB re: 1 μ-in/sec)	Total Number of Impacted Buildings
332 St. Anne Place * (single-family residence)	West	45	55	73	1
Total Vibration Impacts for Category 2 Land Use (Residential)					1
Total Vibration Impacts for Category 3 Land Use (Institutional)					0

* Property was previously identified as 342 St. Anne Place in Draft EIS.

Table 23 summarizes the potential vibration impact along the proposed corridor prior to mitigation.

Table 23
Summary of potential vibration impact prior to mitigation

Residential Buildings Impacted	Institutional Buildings Impacted
1	0

6.9 Construction Vibration Impact Assessment

The primary concern for vibration from construction activities is potential structural damage to buildings. Potential vibration impact from construction activities has been assessed at all properties in close proximity to construction activities associated with the LYNX BLE. In addition, potential short-term impact to vibration sensitive equipment has been assessed. The sensitivity of a structure to potential damage depends primarily on the building's construction (i.e. reinforced concrete or non-engineered timber). The applicable criteria for different building construction types were presented in Section 3.5.

The potential for vibration impact from construction activities depends significantly on the specific contractor's equipment and methods. The following outlines assumptions for which vibration-generating equipment may be used for each type of construction:

- <u>At-grade Track, Station or Parking Lot Construction</u>: Large bulldozer or backhoe, small bulldozer and a vibratory roller for soil compaction.
- <u>Elevated Guideway, Retaining Wall, Bridge, Underpass or Parking Deck Construction:</u> Large bulldozer or backhoe, small bull dozer, vibratory roller for soil compaction and impact pile driving, sonic pile driving or auger drilling for sheet piling and/or pier construction.
- <u>Road</u>: Large bulldozer or backhoe and hoe ram.

For blasting operations, the potential for structural damage to nearby buildings depends on the size of the charge, ground propagation conditions and the building response to vibration. Blasting requires specific procedures to be followed to control the airblast overpressure and ground vibration, so potential impact is not assessed. Further detail on the contractor's requirements for limiting noise and vibration when blasting are provided in Section 7.3.

Vibration projections for potential structural damage at all buildings near construction activities are presented in Appendix I. Vibration projections for potential impact to sensitive equipment at UNC Charlotte CRI are presented in Appendix J. Prior to mitigation, which may include utilizing specific construction equipment or methods, there is the potential for structural damage at 10 properties including the following (Appendix F, Figures 9a and 9b):

- 301 East 7th Street, Philip Carey Company Warehouse (currently Dixie's Tavern, historic)
- 301 East 9th Street, a commercial property with multiple occupants
- 430 East 36th Street, Grinnell Manufacturing Company (currently Newco Fiber Company, historic)
- 300 East 36th Street, Parish and Leonard Tire Company
- 315 East 36th Street, Herrin Brothers Coal & Ice (historic)
- 407 East 36th Street, Johnston Mill (historic)
- 3327 North Davidson Street, Mecklenburg Mill (historic building)
- 601 East Sugar Creek Road, Republic Steel Corporation (currently Warehouse Solutions, historic)

- 4300 Raleigh Street, State Industries
- 332 St. Anne Place, a single-family residence

Prior to mitigation, there is the potential for impact to vibration-sensitive equipment at the following buildings at UNC Charlotte CRI:

- Bioinformatics
- Duke Centennial Hall
- Grigg Hall
- EPIC Building

Potential impact at 301 East 7th Street (Philip Carey Company Warehouse) is due to its proximity (14 feet) to at-grade track and ballast curb construction. At a distance of 14 feet from the proposed ballast curb, a vibratory roller (102 VdB) could generate vibration in excess of the criterion of 98 VdB.

Potential impact at 301 East 9th Street (a commercial building with multiple occupants) is due to its proximity to a proposed retaining wall (five feet) and the proposed 9th Street Station (16 feet). At five feet, a large bulldozer or backhoe (107 VdB), vibratory roller (115 VdB), impact (125 VdB) or sonic (114 VdB) sheet piling and auger drilling (108 VdB) could generate vibration in excess of the criterion of 98 VdB. For construction of the station, a vibratory roller could generate vibration of 100 VdB which is in excess of the criterion.

There is the potential for significant construction vibration impact for several structures at 36th Street in close proximity to proposed retaining walls on 36th Street for the grade separation construction and proposed retaining walls along the NCRR right-of-way (ROW). Potential impact at 430 East 36th Street Grinnell Manufacturing Company (currently Newco Fiber Company) is due to its proximity (five feet) to a proposed retaining wall on 36th Street. At five feet, a large bulldozer or backhoe (107 VdB), vibratory roller (115 VdB), impact (125 VdB) or sonic (114 VdB) sheet piling and auger drilling (108 VdB) could generate vibration in excess of the criterion of 98 VdB.

At 300 East 36th Street (Parish and Leonard Tire Company), there is the potential for construction vibration impact due to its proximity to a proposed retaining wall on the NCRR ROW (16 feet) and a proposed retaining wall on 36th Street (35 feet). For construction of the retaining wall on the NCRR ROW, a vibratory roller (100 VdB) and either impact (110 VdB) or sonic (99 VdB) impact sheet piling could generate vibration in excess of the criterion of 98 VdB. For construction of the retaining wall on 36th Street, impact (100 VdB) sheet piling could generate vibration in excess of the criterion.

At 315 East 36th Street (Herrin Brothers Coal and Ice), there are several structures in close proximity to proposed construction activities including a historic masonry building, metal shed, metal parking garage and steel supported pressure vessels. Construction in this area includes a proposed retaining wall on the NCRR ROW (10 feet from the steel-supported pressure vessels), a retaining wall on 36th Street (15 feet from several structures including the masonry building) and typical at-grade track construction (25 feet from the steel-supported pressure vessels). For construction of the NCRR ROW retaining wall, a vibratory roller (105 VdB) and either impact (116 VdB) or sonic (105 VdB) sheet piling could generate vibration in excess of the criterion for the metal structure (102 VdB). For construction of the 36th Street retaining wall, a vibratory roller (101 VdB) and either impact (111 VdB) or sonic (100 VdB) sheet piling could generate vibration in excess of the criterion for the masonry building (98 VdB). No construction vibration impact is projected for at-grade track construction or for auger drilling.

Potential construction vibration impact at 407 East 36th Street (Johnston Mill) is due to the proximity of two structures to a proposed retraining wall on the NCRR ROW (10 feet) and a proposed retaining wall on 36th Street (30 feet). For construction of the NCRR ROW retaining wall, a vibratory roller (105 VdB) and either impact (116 VdB) or sonic (105 VdB) sheet piling could generate vibration in excess of the criterion for the timber structure (102 VdB). For construction of the 36th Street retaining wall, impact sheet piling (102 VdB) could generate vibration in excess of the criterion for the masonry structure (98 VdB). No construction vibration impact is projected for at-grade track construction or for auger drilling.

At 3327 North Davidson Street (Mecklenburg Mill), there is the potential for construction vibration impact from a proposed retaining wall along the NCRR ROW (25 feet). Impact sheet piling (104 VdB) could generate vibration in excess of the criterion of 98 VdB.

At 601 East Sugar Creek Road (Republic Steel Corporation), construction activities include at-grade track (20 feet from the building) and a proposed retaining wall (12 feet from the building). No construction vibration impact is projected for at-grade track construction. For construction of the retaining wall, a vibratory roller (104 VdB) and either impact (114 VdB) or sonic (103 VdB) sheet piling could generate vibration in excess of the criterion (98 VdB).

At 4300 Raleigh Street (State Industries), there is the potential for construction vibration impact from a proposed retaining wall (30 feet from the building). Impact sheet piling (102 VdB) could generate vibration in excess of the criterion of 102 VdB.

At 332 St. Anne Place (a single-family residence), there is the potential for construction vibration impact from a proposed retaining wall (18 feet from the building). Impact sheet piling (108 VdB) could generate vibration in excess of the criterion of 102 VdB.

Construction vibration impact is not projected at any other historic buildings including 301 East 8th Street (McNeil Paper Company), 5500 North Tryon Street (General Motors Training Company, currently Crossroads Charter High School), 311 East 12th Street (Orient Manufacturing Company, currently Alpha Mill Apartments), 451 Jordan Place (Chadbourn Hosiery Mills) and 600 East Sugar Creek Road (Standard Chemical Products Plant).

The potential for short-term construction vibration impact to sensitive equipment has been assessed at UNC Charlotte Bioinformatics (construction 200 feet from building), Duke Centennial Hall (construction 500 feet from building), Grigg Hall (construction 550 feet from building) and EPIC buildings (construction 1250 feet from building). Based on the outdoor-to-indoor building coupling measurements, 10 VdB of attenuation has been assumed for vibration entering the buildings and propagating to sensitive equipment. Potential impact has been assessed by comparing the overall RMS vibration level of construction activities to the applicable VC criteria. Since the VC criteria are 1/3-octave band criteria, comparing overall construction vibration levels to these criteria is a conservative approach.

At-grade track, retaining wall and underpass construction is proposed near UNC Charlotte. In the Bioinformatics building, vibration from impact pile driving (67 VdB) for retaining wall and underpass construction could be in excess of the VC-B impact criterion for the DNA microarray. At Duke Centennial Hall, a vibratory roller (45 VdB) and either impact (55 VdB) or sonic (44 VdB) sheet piling could generate vibration in excess of the VC-E (42 VdB) criterion. At Grigg

Hall, a vibratory roller (44 VdB) and either impact (54 VdB) or sonic (43 VdB) sheet piling could generate vibration in excess of the VC-E criterion. At the EPIC building, impact pile driving (43 VdB) could potentially generate vibration in excess of the VC-E criterion.

7.0 MITIGATION OF NOISE AND VIBRATION IMPACTS

7.1 Noise Mitigation for Transit Operations

Noise mitigation is considered depending on the need, feasibility, reasonableness and effectiveness of potential options. The FTA states that in considering potential noise impact, severe impacts should be mitigated if at all practical and effective. At the moderate impact level, more discretion should be used, and other project-specific factors should be included in considering mitigation. These factors include the existing noise level, future increase over existing noise levels with the project, the types and number of noise-sensitive land uses affected, the acoustic effectiveness of mitigation options and the cost-effectiveness of mitigating the noise. There is a stronger need for mitigation if a project is proposed in an area currently experiencing high noise levels (Ldn above 65 dBA) from similar surface transportation sources. This is generally the case at sensitive receptors along the existing NCRR/NS mainline where existing Ldn levels range from 70 to 75 dBA.

To mitigate noise impact from train operations, noise control can be considered at the source, along the sound path, or at the receiver. Source noise control options may include special hardware at turnout locations (i.e. spring-rail or moveable-point frogs in place of standard rigid frogs), relocating special trackwork away from sensitive areas and using continuous welded rail. To address wheel squeal from trains operating on tight-radius curves, automated wayside top of rail friction modifier systems provide another source noise control option. These devices put a small amount of lubricant which maintains a constant coefficient of friction onto the top of the rail. This type of lubricant has been shown to reduce or eliminate the potential for wheel squeal.

Noise barrier construction is the most common sound path noise control treatment and can be very effective at reducing noise levels in the community. Noise barriers have been used to mitigate potential noise impact for numerous transit lines across the United States and internationally. Noise barriers are generally effective means of reducing noise from most transit sources when they break the line-of-sight between the source and the receiver. The height necessary for providing sufficient noise reduction depends on the source and receiver heights and the distances from the source and receiver to the barrier. Effective noise barriers can easily reduce noise levels 10 decibels or more depending on the specific implementation.

Noise control at the receiver can be achieved by using building sound insulation treatments. Such treatments may include replacing windows and doors of a sensitive property with windows and doors that provide greater noise reduction properties or adding insulation to the building to seal any air gaps that may allow noise to easily enter. Sound insulation mitigation does not provide any benefit for exterior land uses and is generally considered when other mitigation such as noise barriers are not feasible or effective and/or at receptors that do not have significant exterior land use. Sound insulation treatments are needed to mitigate potential impact if interior noise levels with existing windows and doors would be greater than 45 Ldn. Sound insulation improvements, such as replacing windows and doors with ones that provide greater outdoor-to-indoor noise reduction, would be considered effective if they were to improve existing outdoor-to-indoor noise reduction by five decibels or more and future interior noise levels including project noise sources would be below 45 Ldn. A minimum Sound Transmission

Class (STC) rating of 39 should be used for any window exposed to the noise sources. Since sound insulation improvements are only effective when windows remain closed, it is necessary for buildings to have adequate heating and cooling that allow for windows to be closed, if desired.

A summary of noise mitigation measures proposed for the LYNX BLE is provided in Table 24. Descriptions of these measures are as follows:

- To mitigate the potential moderate noise impact at 311 East 12th Street (Alpha Mill Apartments), a noise barrier approximately 600 feet in length and four feet in height on the east side of the proposed alignment would be reasonable, feasible and effective in reducing impact. Mitigation for these moderate noise impacts is required because existing noise levels are greater than 65 Ldn from noise sources similar to the proposed project, and these moderate impacts should be considered as though they were severe based on FTA guidance. The barrier would be at-grade for approximately 200 feet and then transition to the top of the proposed retaining wall for the elevated guideway which eventually goes over the CSX railroad. The estimated cost for this noise barrier is $72,000 based on $30 per square foot for materials. For the historic building adjacent to the railroad corridor, the noise barrier would reduce noise approximately five decibels and future noise levels would be below the moderate criterion. For the building on the south side of 12th Street, the noise barrier would reduce noise approximately 2-3 decibels, and would not completely mitigate the potential impact. Therefore, this building is a candidate for sound insulation improvements. Sound insulation improvements would be necessary if future interior noise levels with the existing windows would exceed 45 Ldn. During Final Design, the existing outdoor-to-indoor noise reduction of the units will be tested to determine the need for sound insulation improvements. These tests are conducted by playing noise through a speaker outside the building and measuring the levels inside and outside with the windows and doors closed.
- To mitigate potential severe noise impact at 328 Parkwood Avenue and moderate noise impact at 402 East 19th Street near Parkwood Station, installing an automated top of rail friction modifier system on curves LRT NB-5/SB-5 at station number 1055+00 would be reasonable, feasible and effective. With mitigation project noise levels would be four to seven decibels below the moderate noise impact criterion. Automated top of rail friction modifier systems are estimated to cost $15,000 each ($30,000 for both tracks).
- To mitigate potential moderate noise impact at Leafmore Drive, a noise barrier approximately 600 feet long (station number 1192+00 to 1198+00) and approximately 10 feet in height would be effective in reducing future noise levels including noise from existing Amtrak and freight trains by five decibels or more. Mitigation for these noise impacts is required because existing noise levels are greater than 65 Ldn from noise sources similar to the proposed project and these moderate impacts should be considered as though they were severe. The estimated cost of this noise barrier is $180,000 based on $30 per square foot for materials.
- To mitigate potential moderate noise impact at 8503 North Tryon Street/US-29 (Marriott Residence Inn), sound insulation improvements to approximately 16 units, including first and second floor units, closest to North Tryon Street/US-29 would be effective in mitigation potential noise impact. Noise barriers would not be effective mitigation measures for the units due to the large gap that would be needed for the driveway providing access to North Tryon Street/US-29. Mitigation for these noise impacts must be considered because existing noise levels are greater than 65 Ldn from noise sources similar to the proposed project and these moderate impacts should be considered as

though they were severe. Sound insulation improvements would be necessary if future interior noise levels with the existing windows would exceed 45 Ldn. During Final Design, the existing outdoor-to-indoor noise reduction of the units will be tested to determine the need for sound insulation improvements. These tests are conducted by playing noise through a speaker outside the building and measuring the levels inside and outside with the windows and doors closed. Because the hotel already has central heating, ventilation and air-conditioning (HVAC), no improvements to the HVAC system are required. The estimated cost for sound insulation improvements to these 16 units is $400,000 based on a unit cost of $25,000.

- Mitigation for potential severe noise impact at UNC Charlotte Spruce Hall and UNC Charlotte Laurel Hall would include an automated top of rail friction modifier system on curves LRT NB-27/SB-39 at station number 3133+00 and the use of specially-engineered hardware for the double-crossover just west of the proposed UNC Charlotte Station. Specially-engineered hardware may include flange-bearing or spring-rail frogs to minimize the gap in the rail running surface associated with the double-crossover. A frog is the track component in a turnout or crossover that allows the wheels of a train to pass over an intersecting rail. With mitigation, future noise levels at these receptors would be four decibels below the moderate noise impact criterion. Automated top of rail friction modifier systems are estimated to cost $15,000 each ($30,000 for both tracks). Spring-rail frogs are estimated to cost $8,000 each.

Table 24
Summary of proposed noise mitigation

Receptor Locations	Mitigation Location (Station Numbers)	Type of Mitigation	Length (feet)	Side of Tracks	Barrier Height (feet)
311 East 12th Street (Alpha Mill Apartments)	1026+00 to 1032+00	Noise Barrier	600	East	4
	1026+00	Sound Insulation Improvements	n/a	n/a	n/a
328 Parkwood Avenue and 402 East 19th Street	1055+00 Curves LRT NB-5/SB-5	Automated TOR friction modifier	n/a	n/a	n/a
352, 358 and 364 Leafmore Drive	1192+00 to 1198+00	Noise Barrier	600	North	10
8503 North Tryon Street/US-29	3064+00	Sound Insulation Improvements	n/a	n/a	n/a
UNC Charlotte Spruce Hall and Laurel Hall	3133+00 Curve LRT NB-27/SB-39	Automated TOR friction modifier	n/a	n/a	n/a
UNC Charlotte Spruce Hall and Laurel Hall	3135+00	Specially-engineered trackwork at double-crossover	n/a	n/a	n/a

7.2 Vibration Mitigation for Transit Operations

The purpose of vibration mitigation is to minimize adverse effects from a project at sensitive locations. While the consideration of noise mitigation is well-defined, there is more variability in the approach to vibration mitigation and the specific measures that may be considered. The goal for mitigating potential vibration impact from the proposed project is to reduce future vibration below the impact criteria which is 72 VdB for residential properties and 75 VdB for institutional properties. The effectiveness of specific vibration mitigation measures is dependent on several factors such as the mitigation component design, installation technique and frequencies of concern. The following are common vibration mitigation options:

- Resilient rail fasteners are specially-designed fasteners between the rails and the ties that can reduce vibration by five to 10 VdB at frequencies above 30 to 40 Hz.
- Ballast mats are rubber or other elastomer pads placed in the trackform between the ballast and the sub-grade or ground. These can be effective in reducing vibration levels by as much as 10 to 15 VdB at frequencies above 25 Hz.
- Tire Derived Aggregate (TDA), also known as shredded tires, has also been used to provide track vibration isolation. 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 equal or superior to that of ballast mats. While this is a low-cost option, it has only been installed on two U.S. light rail transit systems (San Jose and Denver).
- Resiliently supported ties have a rubber or other resilient material placed between the ties and the ballast. These ties are can be effective in reducing vibration by up to 10 VdB at frequencies above 15 Hz.
- Floating slab trackforms consist of a concrete slab supported on resilient elements such as rubber or elastomer pads. Floating slabs can be very effective at controlling vibrations down to frequencies below 10 Hz. Drawbacks towards floating slab trackforms include difficulties in designing for heavy axle loads, difficulties in designing for outdoor exposure to the elements and the relatively high cost.
- Similar to noise, special trackwork such as turnouts and crossovers increase vibration levels of the trains. Mitigation may include using special hardware (i.e. flange-bearing or moveable-point frogs in place of standard rigid frogs), relocating special trackwork away from sensitive areas and using continuous welded rail rather than jointed rail.
- Maintenance programs can also be essential for controlling vibration. Maintaining a proper wheel/rail profile, minimizing the number and extent of wheel flats and minimizing potential rail corrugation are important factors. Rail grinding, truing wheels and monitoring wheel/rail profiles can be effective means of reducing potential vibration impact.

For mitigation of the potential vibration impact at 332 St. Anne Place (Appendix F, Figure 7), installing 150 feet of ballast mats or TDA in the Blue Line trackform would be effective. These track vibration isolation treatments can reduce vibration levels from light rail trains by up to 15 VdB. With mitigation, vibration levels from Blue Line trains would be below the vibration impact criterion. The estimated cost for vibration isolation such as ballast mats is $54,000 based $180 per track-foot and $18,000 for TDA based on $60 per track-foot for 300 track-feet of treatment. Maintenance of either ballast mats or TDA should be minimal as they have not been shown to cause any drainage problems or degradation of performance. A summary of the proposed vibration mitigation is provided in Table 25 below.

Table 25
Summary of proposed vibration mitigation

Receptor Location	Length (feet)	Mitigation Start (Station Number)	Mitigation End (Station Number	Type of Mitigation
332 St. Anne Place	150	1202+50	1204+00	Ballast Mats or TDA

7.3 Construction Noise and Vibration Mitigation

Construction activities will be carried out in compliance with all applicable local noise regulations including the City of Charlotte Noise Ordinance and FTA guidelines for limiting construction vibration and the potential for structural damage to nearby buildings or impact to vibration-sensitive equipment. The contractor will monitor construction noise levels and use noise control measures to reduce noise emissions and potential impact to sensitive receptors where necessary and feasible. Mitigation for potential vibration impact from construction activities includes monitoring vibration levels near sensitive buildings and equipment and utilizing specific construction equipment or methods where necessary. The following outlines general guidelines that the contractor will follow to mitigate potential construction noise and vibration impact.

1. General Requirements
   - The contractors shall prepare a <u>Construction Noise and Vibration Control Plan</u> including;
     - where and what type of construction equipment and methods will be used during respective time periods (i.e. day or night),
     - noise and vibration predictions at locations where potential impact may occur and
     - mitigation measures that will be implemented to minimize potential impact.
   - The contractors shall involve an Acoustical Engineer to ensure noise and vibration levels are effectively managed and excessive noise and vibration is prevented.
     - The contractors shall provide an opportunity via a phone number and/or website for the community to log complaints in regard to excessive noise and vibration. The Acoustical Engineer shall respond to these complaints and coordinate with the Construction Manager to resolve noise and vibration complaints.
     - For blasting operations, the contractors shall consult with nearby sensitive receptors to schedule for least disturbing times and provide advanced notice of blasting operations. The contractor shall prepare a Blasting Plan to be approved by CATS and others designated by CATS (eg. UNC Charlotte).
     - For blasting operations near UNC Charlotte, the contractor shall follow specific notification procedures to avoid damages to vibration sensitive equipment. The contractor shall provide a one week advanced notice of the start of blasting operations. The contractor shall facilitate a pre-blast meeting to clearly define the entire schedule and scope of sequence of blasting. Attendees of the meeting shall include the UNC Charlotte Facilities, UNC Charlotte Police & Public Safety, UNC Charlotte Safety Office, Charlotte Fire Department, Testing agency, and any Engineer of record. The schedule of blasting operations shall include the date, starting time, and extent of time of blasting operation each day. Blasting shall be scheduled in batches to the extent possible. The schedule shall be kept current at all times. The contractor shall provide a twenty-four (24) hour notification for each blast.
   - The contractors will conduct noise and vibration monitoring at locations where potential impact from construction activities may occur. The locations are listed in Table 19 (noise) and Appendix I (vibration).
     - The contractors shall use a Type I or Type II sound level meter to monitor noise emissions from construction activities.
     - The contractors shall conduct reference noise emission testing of construction equipment to be used at locations where potential construction noise impact may occur. Maximum construction equipment noise emissions measured at a reference distance of 50 feet under full load are presented in Appendix K.

  - The contractors shall monitor construction vibration levels at locations where potential construction vibration impact may occur including potential structural damage to buildings and impact to vibration-sensitive equipment.
  - For blasting operations, the contractors will monitor airblast overpressure and ground vibration.
  - The contractors shall prepare a weekly Noise and Vibration Monitoring Report.
- The contractors shall conduct pre-construction and post-construction surveys of buildings with the potential for structural damage identified in Section 6.9 and all structures within 500 feet of blasting operations. Surveys shall include descriptions of house, sketch of floor plans, description of foundation and basement and photographs (not video) of potential cosmetic or structural damage. In locations of existing cracks, methods should be employed to measure potential crack propagation due to construction activities.
  - The contractors shall prepare reports on the Pre and Post-construction Surveys of Structural and Cosmetic Damage at buildings with the potential for structural damage identified in Section 6.9

2. The contractors shall perform work within permissible noise and vibration levels, schedule limitations and work procedures.
   - General construction noise limits are presented in Section 3.4 and specific construction noise limits at locations currently identified where potential impact may occur are presented in Section 6.4
   - City of Charlotte Noise Ordinance does not allow construction machinery to be used between 9:00pm and 7:00am in any part of the city zoned for residential use, or within 300 feet of any structure used as a residence regardless of its zoning. Nighttime construction restrictions do not apply to hotels and motels, so potential impact is assessed for nighttime residential land use.
   - At UNC Charlotte, construction is not allowed near residence halls prior to 8:00 am nor allowed within 200 feet of campus building during the week of final examinations.
   - General construction vibration limits to reduce the potential for structural damage are presented in Section 3.5.
   - Blasting operations should be conducted to prevent airblast overpressure in excess of 0.01 psa and ground vibration in excess of limits specified in Section 3.5 Table 9 based on building construction.
   - Specific vibration limits from construction equipment measured at buildings with the potential for structural damage from construction activities are presented in Appendix I.
   - General vibration limits to reduce the potential impact on vibration-sensitive equipment are presented in Section 3.3
   - Specific vibration limits from construction equipment measured at vibration-sensitive equipment are presented in Appendix J.

3. The contractors shall implement mitigation measures to minimize noise and vibration emissions and adhere to the permissible noise and vibration levels.
   - Typical construction noise control measures include the following:
     - The location of construction equipment plays a critical role in potential impact at sensitive receptors. Mitigation should include locating stationary construction equipment as far as possible from noise-sensitive sites.
     - Many types of construction equipment include diesel engines which can be the most significant noise source. Therefore, reducing engine noise is often a key

element to mitigating potential impact. Mitigation for engine noise may include use of shields, shrouds or intake and exhaust mufflers.
  - Most wheeled and tracked construction equipment is required to have back-up alarms for safety purposes. Due to their tonal character, these alarms are often a significant concern for noise impact. Special back-up alarms may be implemented including ambient-adjusted alarms which only sound five decibels higher than ambient conditions or "quackers" which have a less tonal character.
  - The use of steel plates on roadways can increase noise and vibration levels. Mitigation may include detouring traffic around plates, using thicker plates or placing a resilient material such as rubber under the plates.
  - Construction vehicles such as dump trucks and concrete mixers often contribute significantly to the noise conditions. Mitigation may include re-routing truck routes to minimize exposure to sensitive receptors.
  - Acoustic enclosures may be needed to reduce emissions from small construction equipment such as jackhammers and generators.
  - Temporary noise barriers or noise blankets can be installed between construction equipment and sensitive receptors to provide significant noise reduction (typically five to 15 decibels).
  - Generators can be a significant contributor to noise emissions. Noise mitigation may include limiting the size of generators, the locations they may be placed and/or the duration of their use.
  - Impact noise from dropping materials during loading and unloading activities can generate brief, but high noise levels. To reduce impact noise, lining chutes and bins with sound-deadening material such as rubber mats can significantly reduce noise.
  - Breaking up pavement and concrete can generate significant noise emissions. To mitigate potential noise impact, using concrete crushers or pavement saws rather than hoe rams can reduce noise. In addition increasing the number of perpendicular saw cuts can further reduce noise.
- Mitigation for potential vibration impact from construction activities includes utilizing specific construction equipment or methods. Typical construction vibration control measures include the following:
  - To mitigate potential construction vibration impact from large bulldozers or backhoes, small bulldozers can be used in almost all situations without potential vibration impact.
  - To mitigate potential impact associated with the use of a vibratory roller to compact soil, a static roller can be used which generates significantly less vibration.
  - Impact and sonic sheet pile driving can generate significant vibration. To mitigate potential construction vibration impact for retaining wall construction, a gravity or cantilevered retaining wall could be used since construction of these types of walls primarily involve excavation rather than pile driving. If sheet piling is required, low-vibration sheet piling methods should be used such as those that use hydraulic push-in equipment. If retaining walls are constructed with soil nailing methods, drilling for the insertion of steel reinforcing elements would generate less vibration than impact of sonic sheet pile driving.
  - For mitigation of potential vibration impact from pier pile driving for bridge construction, piers can be drilled in to generate significantly less vibration.
  - Using truck routes that minimize exposure to sensitive receptors and maintaining smooth roadway surfaces.

- For blasting operations, mitigation may include use a small-charge test blast at each new site to establish propagation conditions, minimizing the charge-per-delay and/or use weighted covers or blasting mats, if needed.

Specific construction noise and vibration mitigation measures to be implemented near sensitive receptors (see Table 1 for noise and Table 2 for vibration in Section 1.5) will be identified by the contractor in the Construction Noise and Vibration Control Plan. At most receptors, construction noise would only need to be reduced five decibels to mitigate potential construction noise impact. This level of noise reduction could be achieved relatively easily with the mitigation measures described above.

Potential structural damage from construction activities has been identified at several buildings for a range of construction activities including impact or sonic pile driving, auger drilling, vibratory rolling and large bulldozers. The actual construction methods and equipment used for the project will depend on the individual contractors approach and the actual vibration levels will depend on site conditions (i.e. soil types and presence or rock). The type of construction and equipment required for the project is not expected to be extraordinarily different than other transit projects and it is anticipated that the contractors will be able to adhere to the vibration limits through the use of specialized construction methods and equipment as described above.

Appendix A Measurement Site Photographs

Figure 1
Long-term noise Site 1 – Pines Mobile Park, 5635 North Tryon Street/US-29

Figure 2
Reference noise measurement site at East 11th & Brevard Street (TPSS)

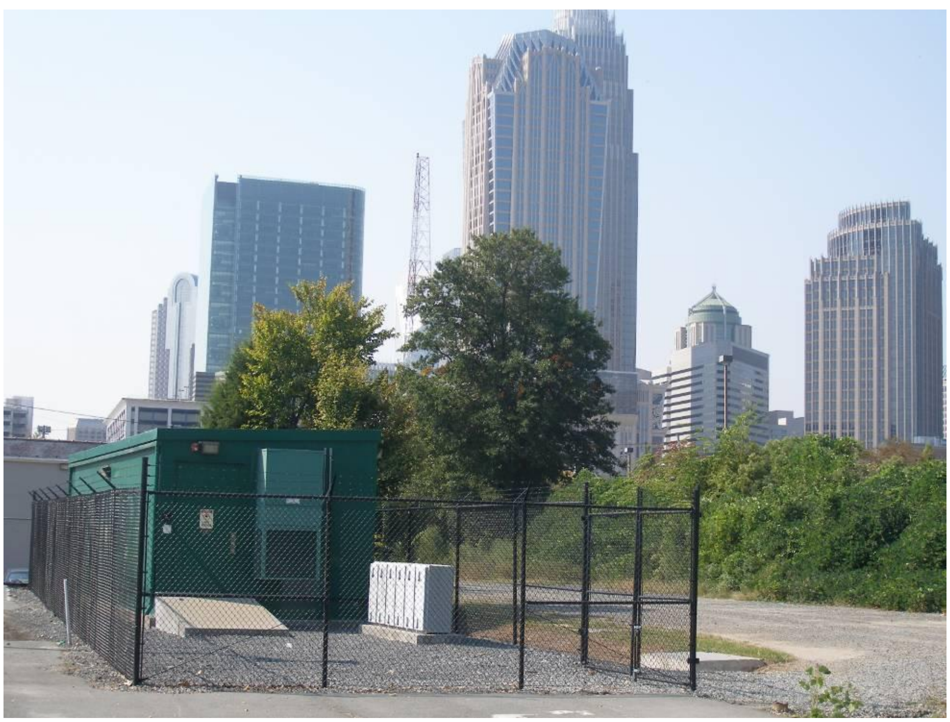


Figure 3
Reference noise measurement site at Remount Road (LVR & crossing bells)

Figure 4
Reference noise measurement site at South Corridor Light Rail Vehicle Maintenance Facility (LRV)

Figure 5
Vibration propagation measurement site at East 11th Street & Brevard Street

Figure 6
Vibration propagation measurement site at North Davidson Street

Figure 7
Vibration propagation measurement site at North Park Mall

Figure 8
Vibration measurement site at North Park Mall (Amtrak & freight trains)

Figure 9
Vibration propagation measurement site at Carolinas Medical Center - University

Figure 10
Vibration propagation measurement site at UNC Charlotte

Figure 11
Vibration measurement site at UNC Charlotte Bioinformatics Building

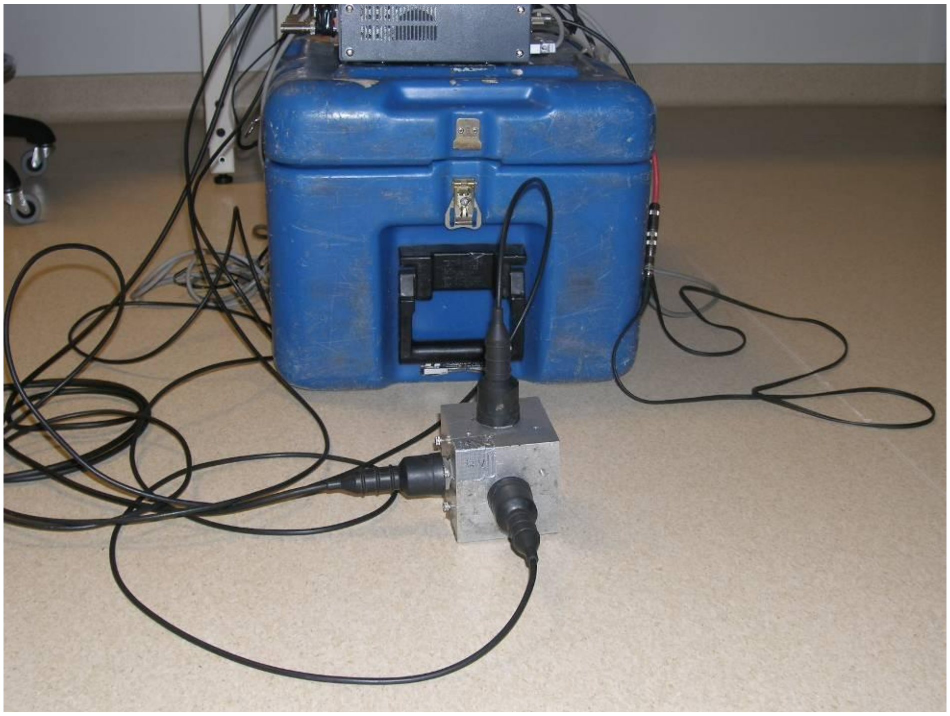


Figure 12
Vibration measurement site at UNC Charlotte Duke Hall Metrology Lab

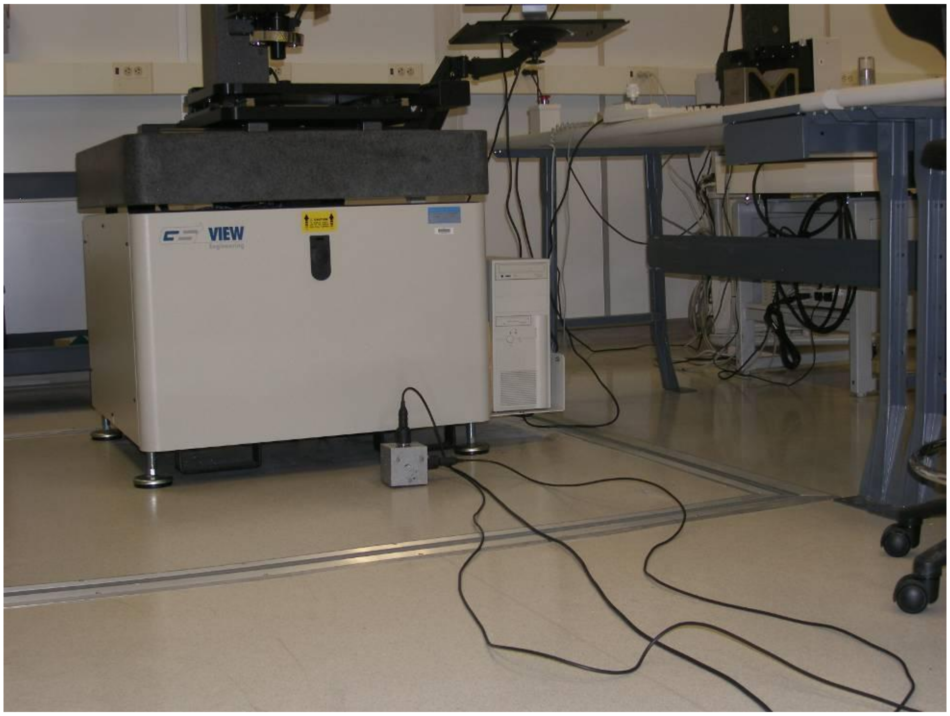


Figure 13
Vibration measurement site at UNC Charlotte Duke Hall: SEM

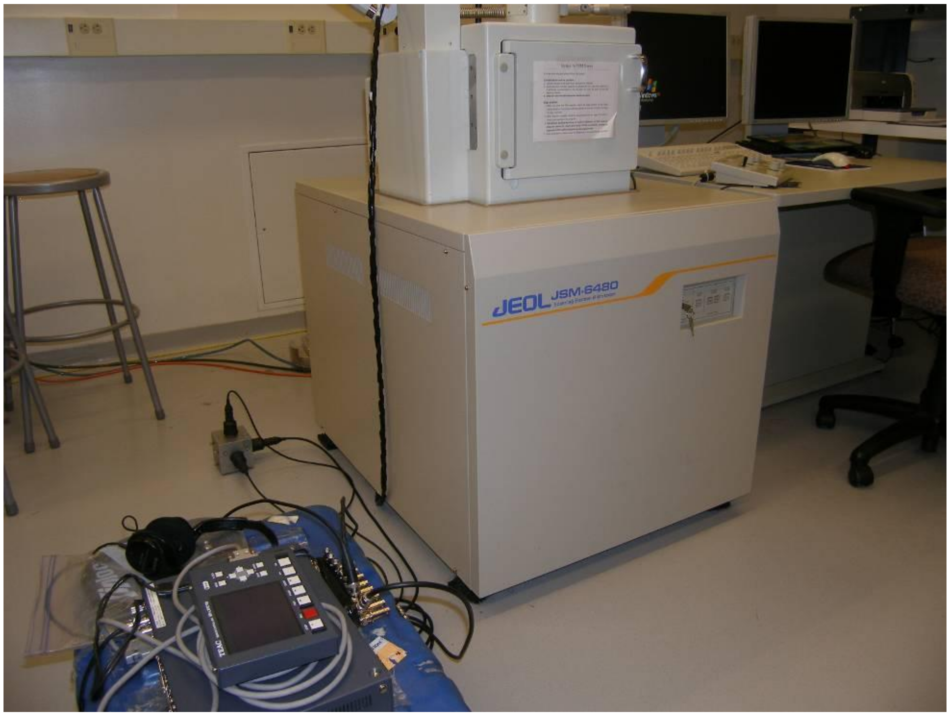


Figure 14
Vibration measurement site at UNC Charlotte Grigg Hall: Atomic Force Microscope

Figure 15
Vibration measurement site at UNC Charlotte Grigg Hall:SEM

Figure 16
Vibration measurement site at UNC Charlotte Grigg Hall: E-Beam Lithography

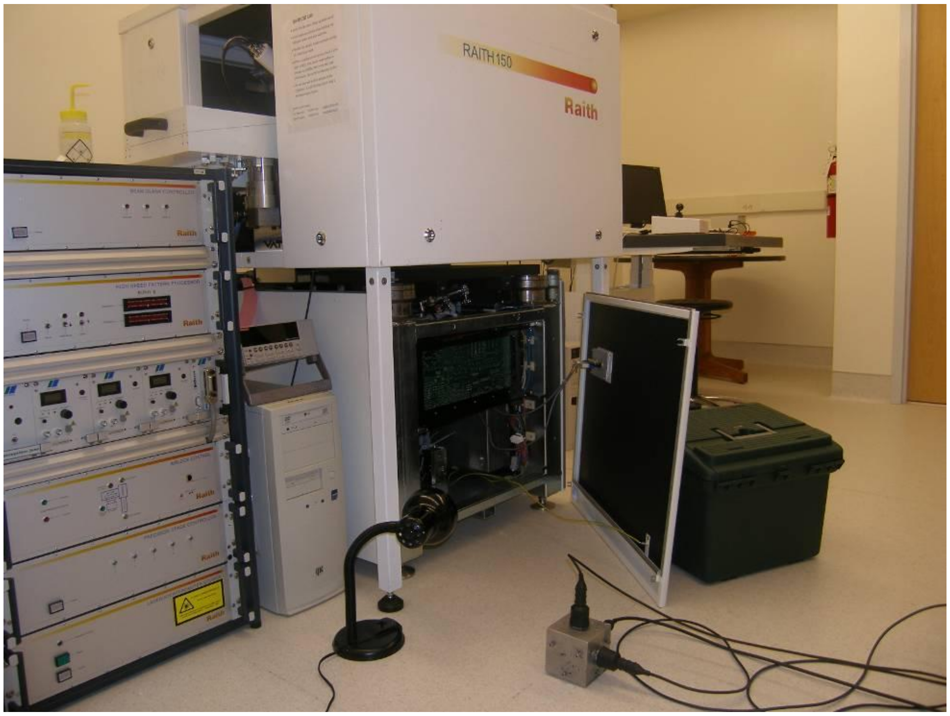


Figure 17
Vibration measurement site at UNC Charlotte Grigg Hall: Six Axis Alignment

Figure 18
Vibration measurement site at UNC Charlotte Grigg Hall: Clean Room Lithography

Figure 19
Vibration propagation measurement site at Kirk Field Farms

Figure 20
Force density measurement site for Blue Line trains at Remount Road

Appendix B Vibration Propagation Line Source Transfer Mobility Results

Table 1
LSTM Regression Results for Site 1: East 11th Street and North Brevard Street

1/3-Octave Band Center Frequency [Hz]	Line Source Transfer Mobility Regression Coefficients LSTM = A + B*10*Log(Distance) + C*10*Log(Distance)^2		
	A	B	C
6.3	17.5	1.9	0
8	16.0	2.6	0
10	14.3	2.5	0
12.5	17.0	3.5	0
16	29.3	9.7	0
20	57.7	22.1	0
25	68.7	27.1	0
31.5	71.4	27.3	0
40	74.9	28.7	0
50	85.5	35.0	0
63	99.9	44.9	0
80	111.1	55.4	0
100	104.4	56.5	0
125	80.6	47.2	0
160	68.0	42.7	0
200	50.3	35.2	0
250	44.5	34.8	0
315	33.4	30.6	0
400	23.5	25.9	0

Figure 1
LSTM Results for Site 1: East 11th Street and North Brevard Street

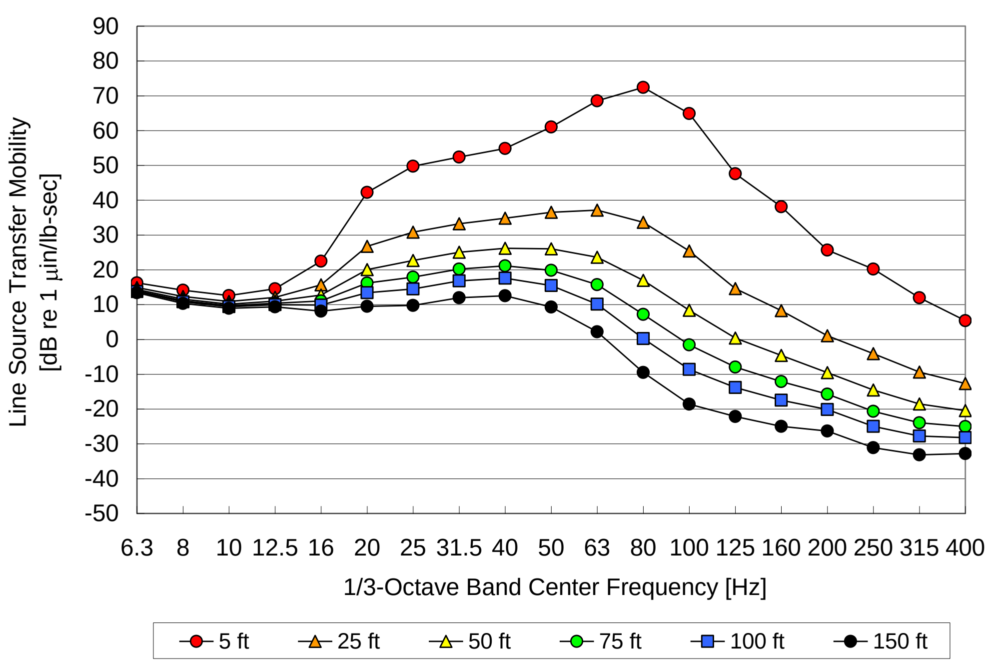


Table 2
LSTM Regression Results for Site 2: North Davidson Street and Herrin Avenue

1/3-Octave Band Center Frequency [Hz]	Line Source Transfer Mobility Regression Coefficients LSTM = A + B*10*Log(Distance) + C*10*Log(Distance)^2		
	A	B	C
6.3	31.5	9.7	0
8	46.2	14.9	0
10	56.9	16.1	0
12.5	56.4	14.0	0
16	58.3	14.1	0
20	61.0	15.2	0
25	63.0	16.3	0
31.5	70.2	20.9	0
40	79.7	27.4	0
50	82.7	31.3	0
63	86.0	37.9	0
80	70.8	34.5	0
100	73.0	39.7	0
125	79.9	47.3	0
160	63.7	39.6	0
200	51.6	34.2	0
250	53.3	36.3	0
315	58.3	40.6	0
400	52.4	41.2	0

Figure 2
LSTM Results for Site 2: North Davidson Street and Herrin Avenue

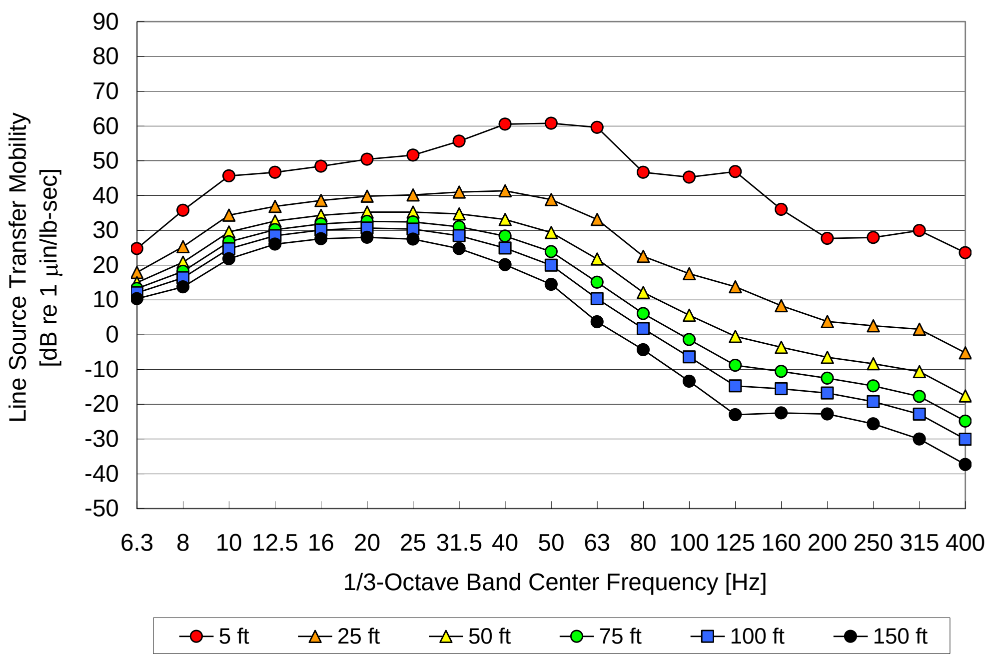


Table 3
LSTM Regression Results for Site 3: North Park Mall

1/3-Octave Band Center Frequency [Hz]	Line Source Transfer Mobility Regression Coefficients $LSTM = A + B*10*Log(Distance) + C*10*Log(Distance)^2$		
	A	B	C
6.3	44.7	14.1	0
8	53.3	16.2	0
10	50.2	12.2	0
12.5	50.3	10.8	0
16	54.3	12.1	0
20	59.8	13.9	0
25	64.9	15.7	0
31.5	70.5	17.9	0
40	75.6	21.0	0
50	81.7	25.6	0
63	91.0	33.4	0
80	96.0	40.2	0
100	91.9	43.5	0
125	80.7	42.3	0
160	83.6	49.4	0
200	69.6	45.8	0
250	57.9	41.9	0
315	42.0	34.8	0
400	28.2	27.5	0

Figure 3
LSTM Results for Site 3: North Park Mall

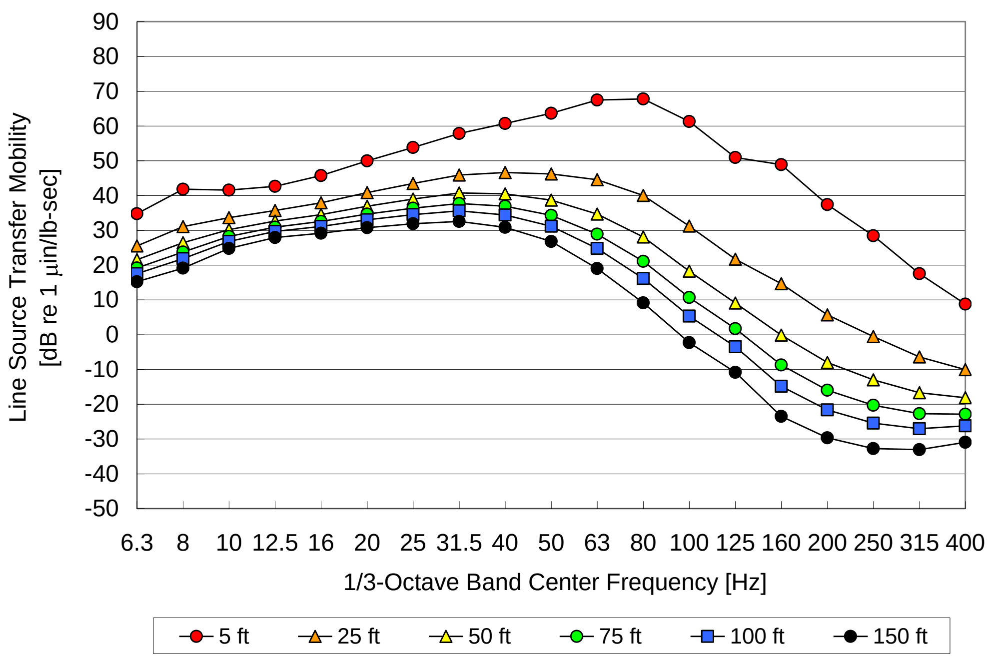


Table 4
LSTM Regression Results for Site 4: Carolinas Medical Center - University

1/3-Octave Band Center Frequency [Hz]	Line Source Transfer Mobility Regression Coefficients LSTM = A + B*10*Log(Distance) + C*10*Log(Distance)^2		
	A	B	C
6.3	25.9	-6.4	0
8	31.0	-10.8	0
10	47.3	-19.4	0
12.5	54.3	-15.2	0
16	51.8	-12.5	0
20	54.0	-13.6	0
25	56.8	-15.4	0
31.5	63.8	-19.5	0
40	72.9	-25.7	0
50	76.7	-29.8	0
63	74.4	-31.3	0
80	79.4	-37.5	0
100	83.7	-43.3	0
125	83.9	-47.1	0
160	82.1	-49.8	0
200	52.9	-36.1	0
250	45.9	-36.2	0
315	44.2	-36.4	0
400	48.4	-39.4	0

Figure 4
LSTM Results for Site 4: Carolinas Medical Center - University

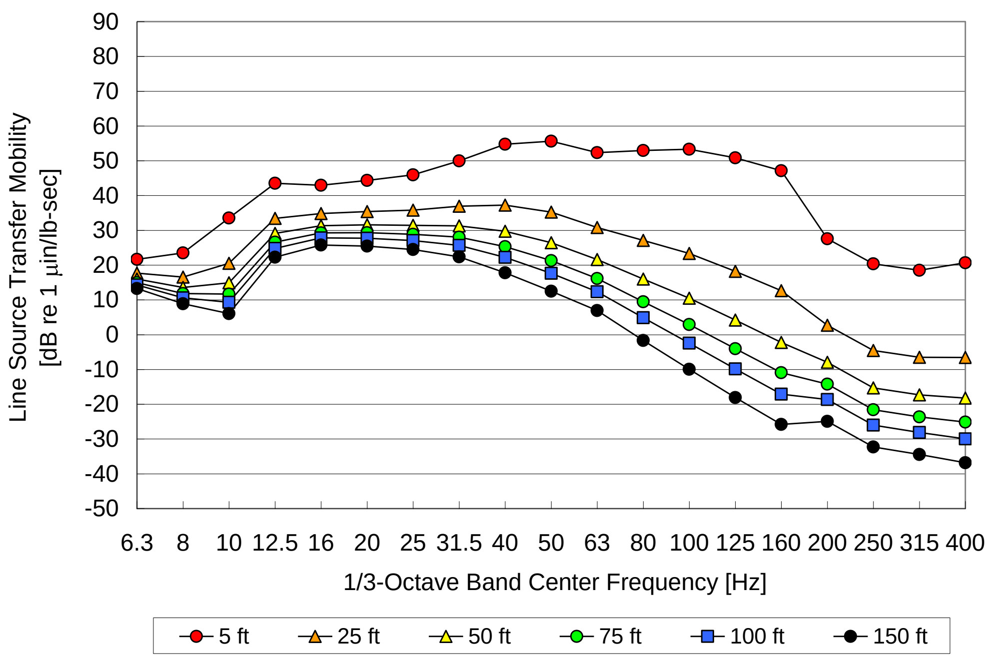


Table 5
LSTM Regression Results for Site 5: UNC Charlotte – CRI

1/3-Octave Band Center Frequency [Hz]	Line Source Transfer Mobility Regression Coefficients LSTM = A + B*10*Log(Distance) + C*10*Log(Distance)^2		
	A	B	C
6.3	27.1	-6.5	0
8	32.9	-9.7	0
10	45.0	-12.5	0
12.5	57.6	-16.6	0
16	61.9	-18.5	0
20	64.7	-19.7	0
25	70.6	-22.9	0
31.5	77.1	-26.5	0
40	86.1	-31.2	0
50	96.3	-36.8	0
63	104.0	-42.0	0
80	112.1	-47.5	0
100	113.2	-50.0	0
125	104.5	-50.2	0
160	77.6	-41.5	0
200	47.0	-28.9	0
250	40.9	-27.2	0
315	36.2	-26.6	0
400	26.6	-24.2	0

Figure 5
LSTM Results for Site 5: UNC Charlotte – CRI

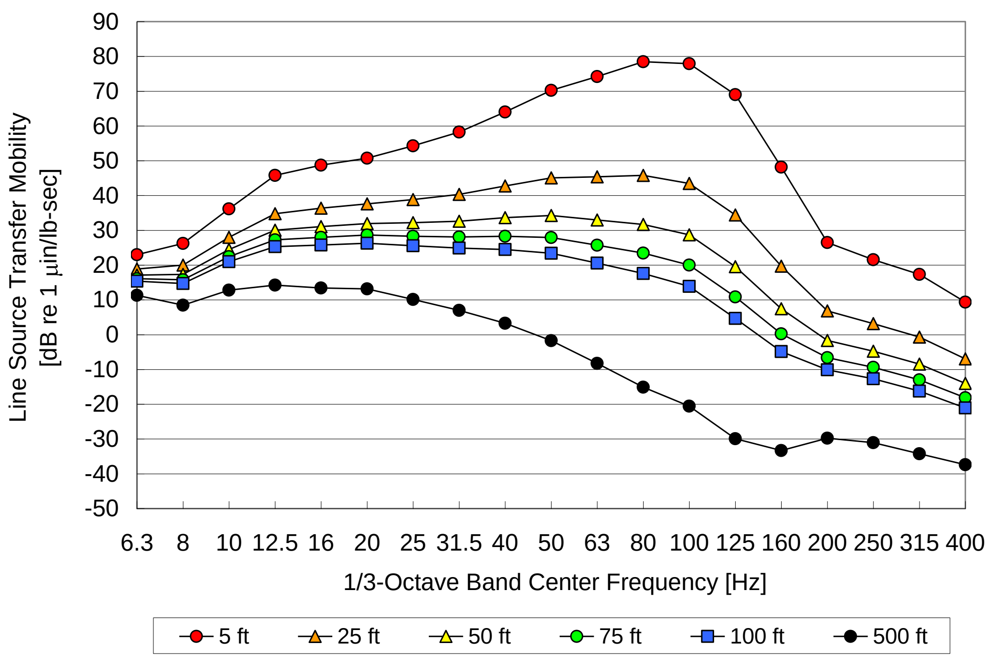


Table 6
LSTM Regression Results for Site 6: Kirk Farm Fields

1/3-Octave Band Center Frequency [Hz]	Line Source Transfer Mobility Regression Coefficients LSTM = A + B*10*Log(Distance) + C*10*Log(Distance)[2]		
	A	B	C
6.3	27.4	-7.4	0
8	35.5	-10.4	0
10	52.5	-13.8	0
12.5	60.0	-14.3	0
16	54.4	-10.4	0
20	53.2	-8.9	0
25	58.6	-10.8	0
31.5	73.5	-18.7	0
40	87.2	-26.9	0
50	100.2	-36.8	0
63	106.9	-45.0	0
80	113.2	-52.2	0
100	104.3	-50.8	0
125	76.0	-40.6	0
160	55.3	-32.0	0
200	37.1	-22.2	0
250	25.2	-16.2	0
315	19.4	-15.2	0
400	13.9	-14.6	0

Figure 6
LSTM Results for Site 6: Kirk Farm Fields

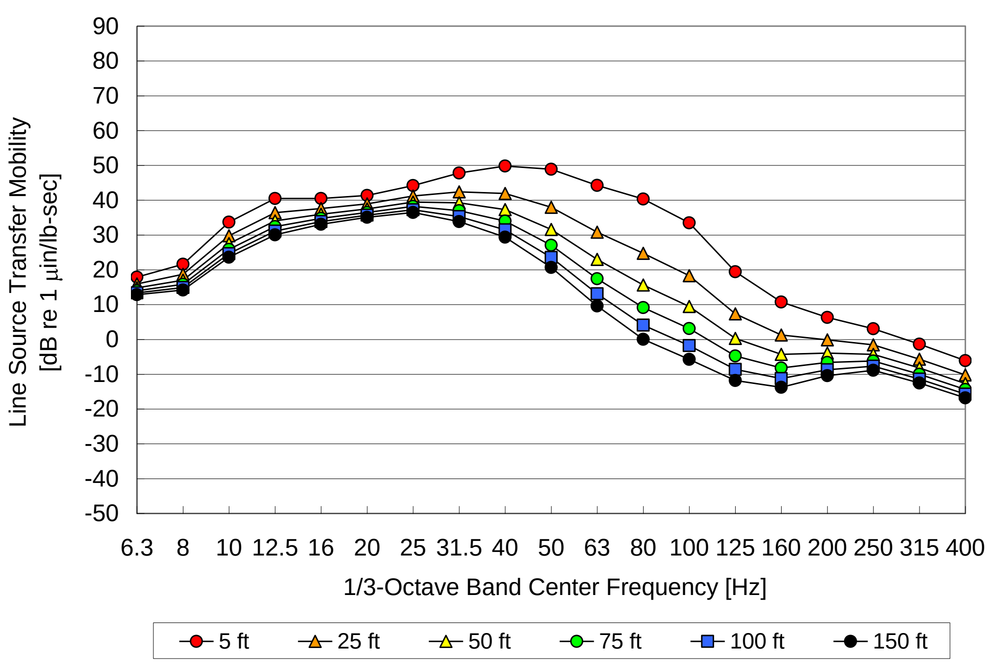


Table 7
LSTM Regression Results for Force Density Site

1/3-Octave Band Center Frequency [Hz]	Line Source Transfer Mobility Regression Coefficients LSTM = A + B*10*Log(Distance) + C*10*Log(Distance)^2		
	A	B	C
6.3	35.4	-12.6	0
8	40.4	-16.3	0
10	53.6	-18.6	0
12.5	50.6	-14.1	0
16	43.4	-10.2	0
20	42.2	-9.9	0
25	45.1	-11.8	0
31.5	55.1	-17.3	0
40	65.3	-21.9	0
50	73.3	-25.5	0
63	76.8	-27.5	0
80	80.3	-32.6	0
100	83.5	-38.5	0
125	83.6	-43.0	0
160	78.3	-43.2	0
200	62.6	-37.9	0
250	43.6	-30.5	0
315	35.7	-27.6	0
400	25.1	-22.7	0

Figure 7
LSTM Results for Force Density Site

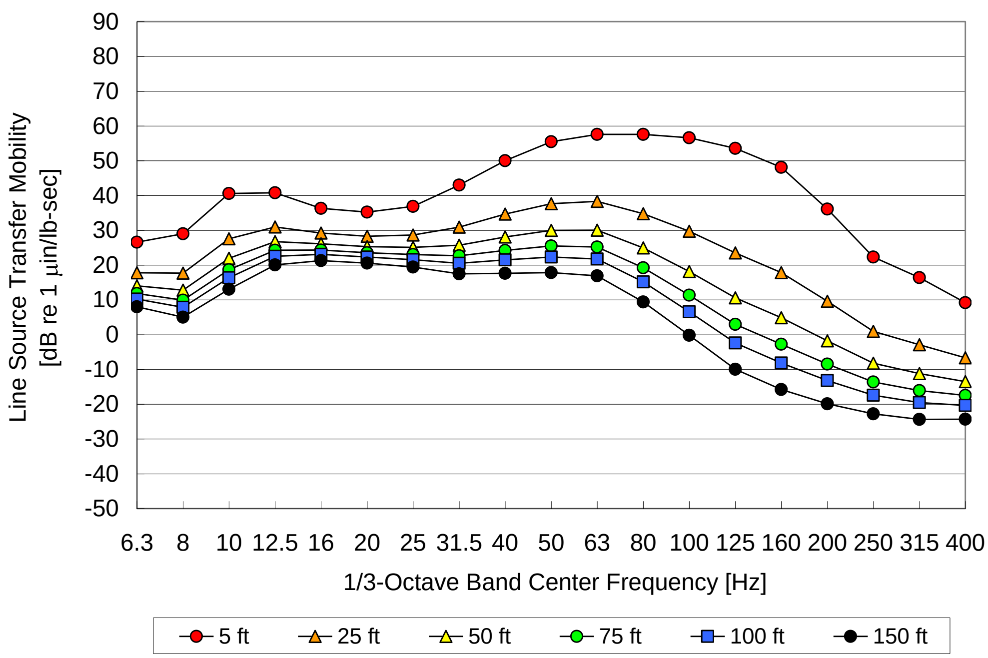
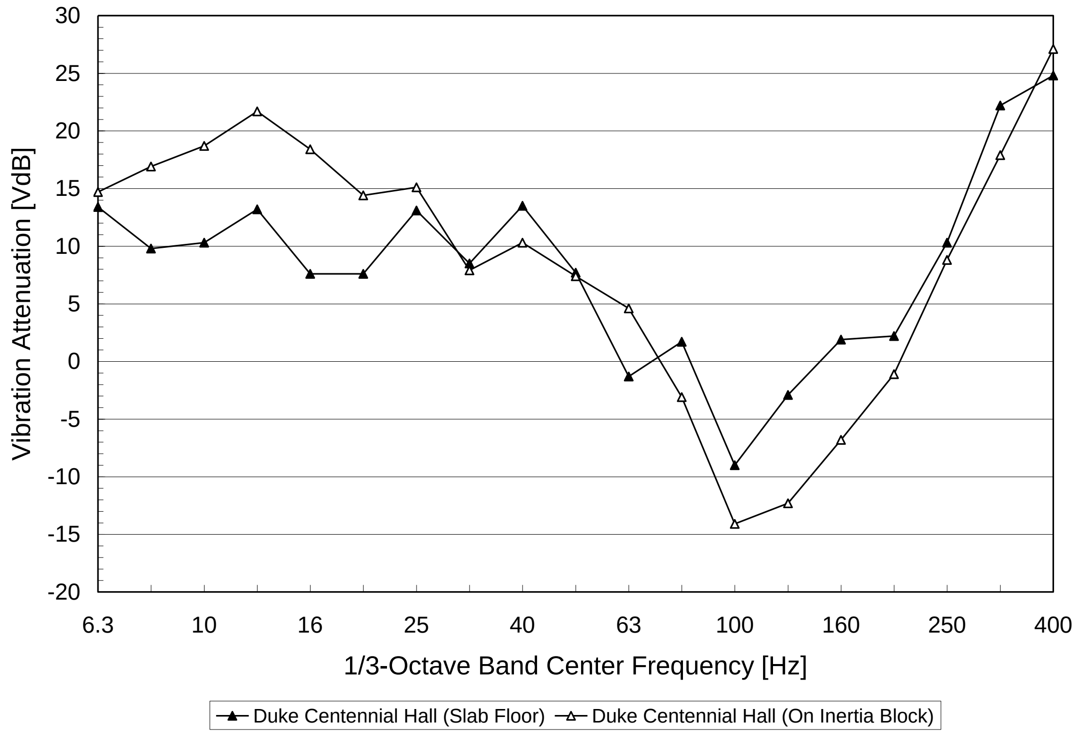


Figure 8
Building Coupling Loss Measured at CRI Duke Centennial Hall



Appendix C Amtrak and Freight Vibration Measurement Results

Figure 1
Vibration spectra for freight trains on NCRR/NS mainline at North Park Mall

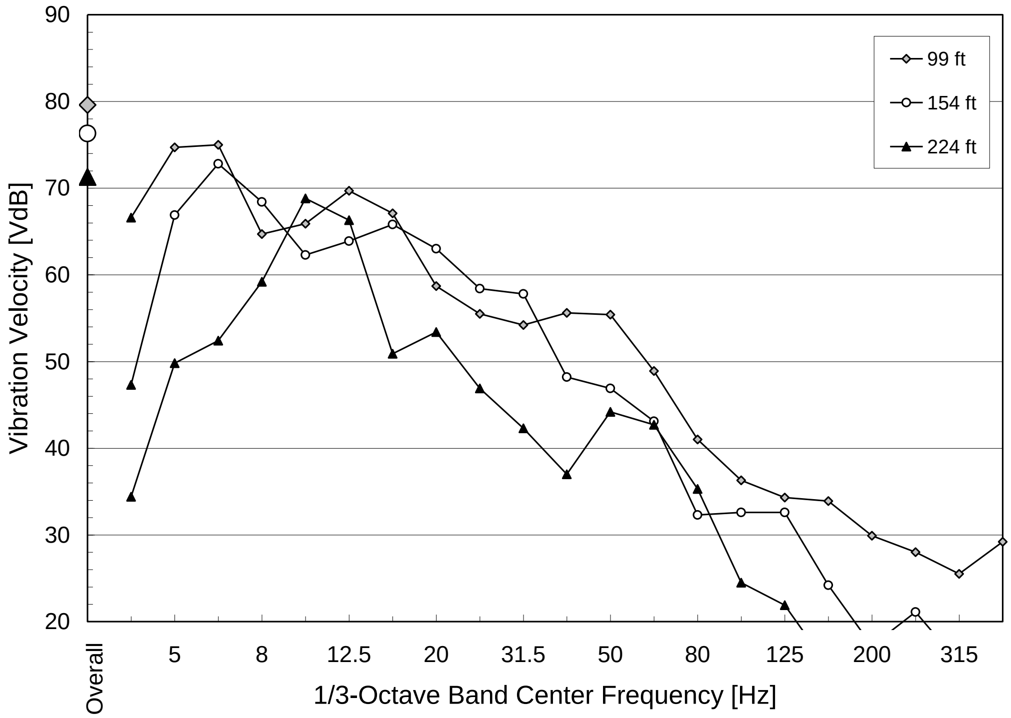
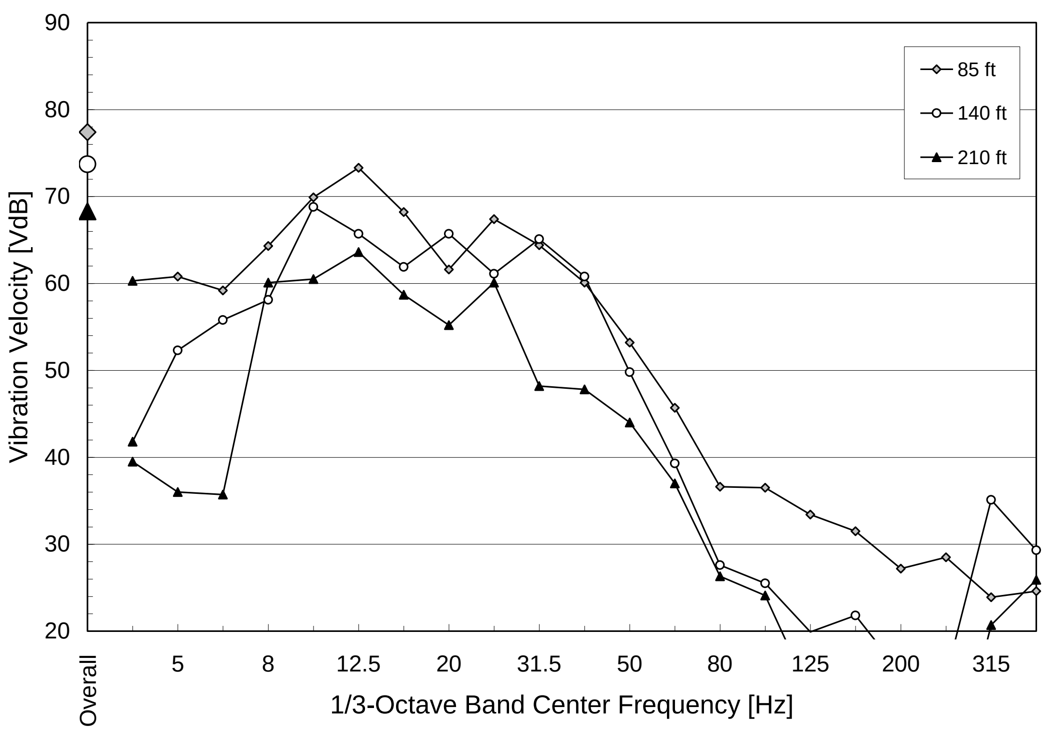


Figure 2
Vibration spectra for Amtrak trains on NCRR/NS mainline at North Park Mall



Appendix D Ambient Vibration Measurements

Figure 1
Ambient vibration spectra at Duke Centennial Hall - Room 240: SEM

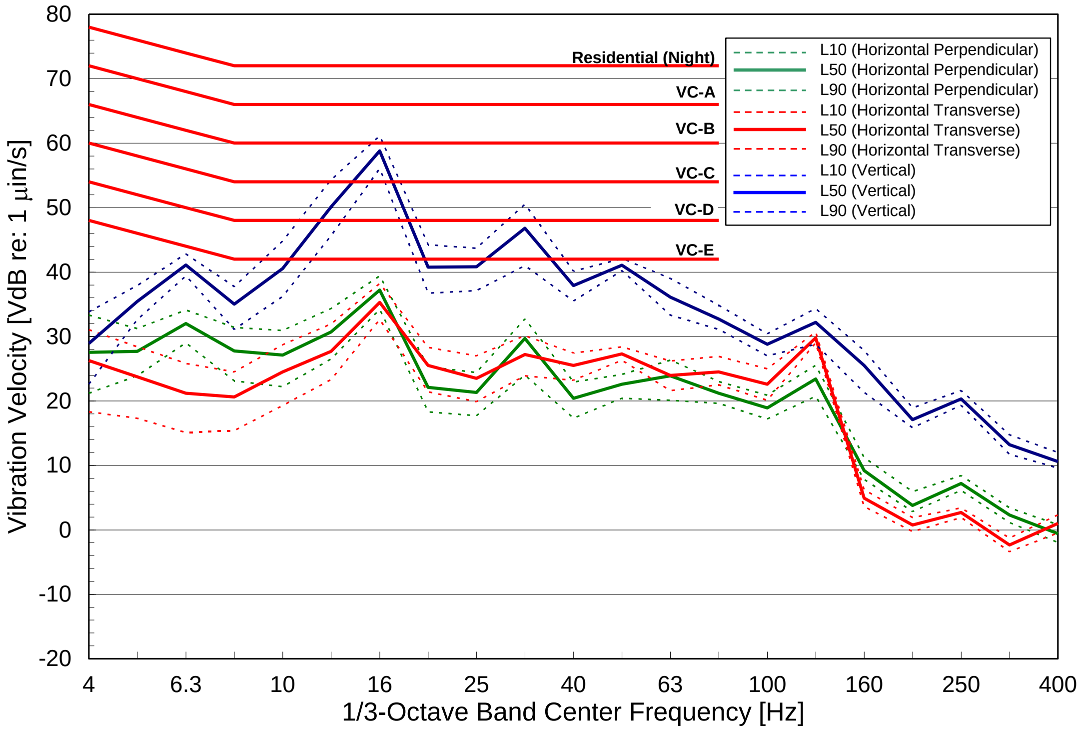


Figure 2
Ambient vibration spectra at Duke Centennial Hall – Room 138C on inertia block: Metrology Lab, atomic force microscope, diamond machining center

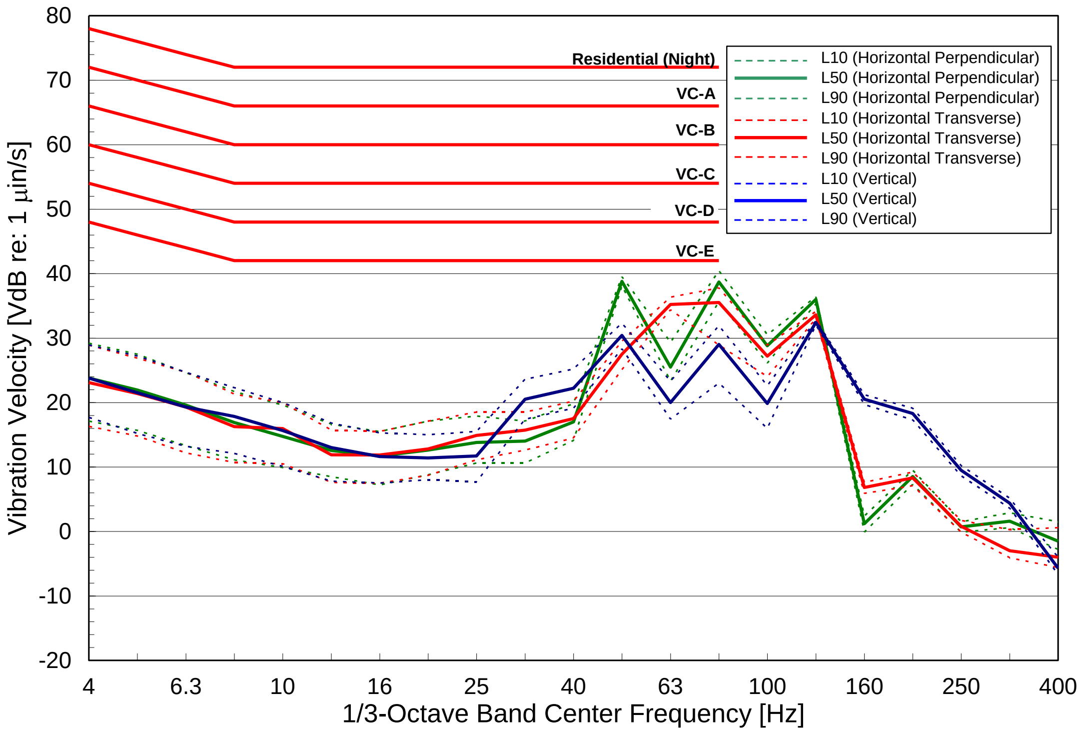


Figure 3
Ambient vibration spectra at Duke Centennial Hall – Room 138C on ground floor: Metrology Lab, atomic force microscope, diamond machining center

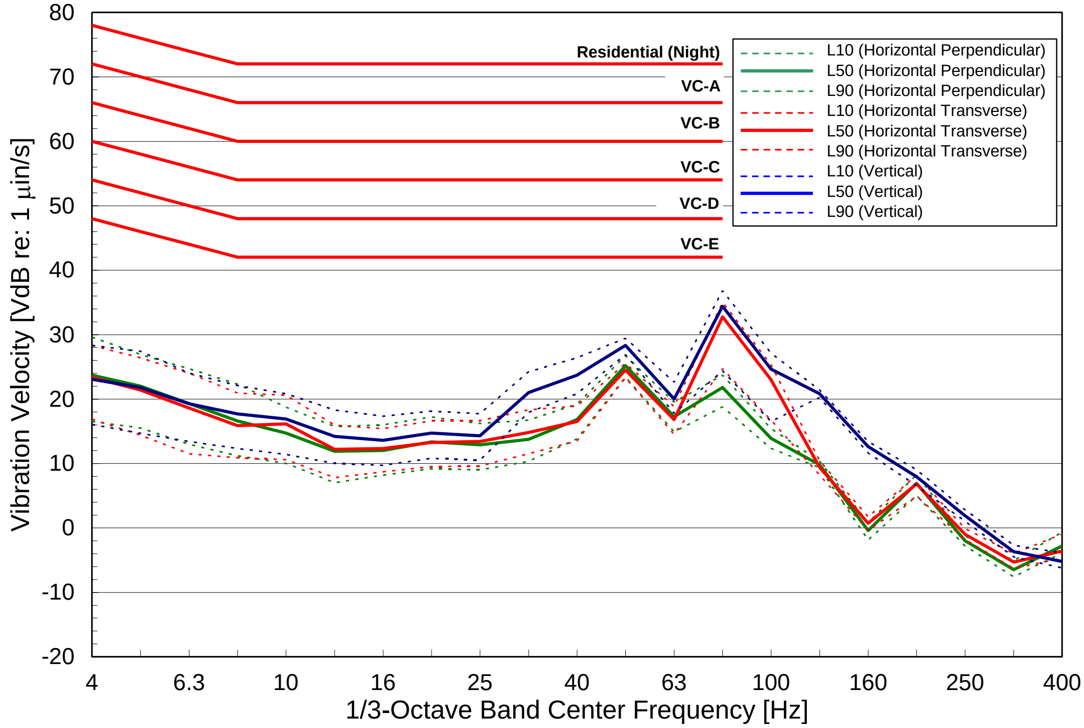


Figure 4
Ambient vibration spectra at Bioinformatics – Room 332A: DNA Microarray

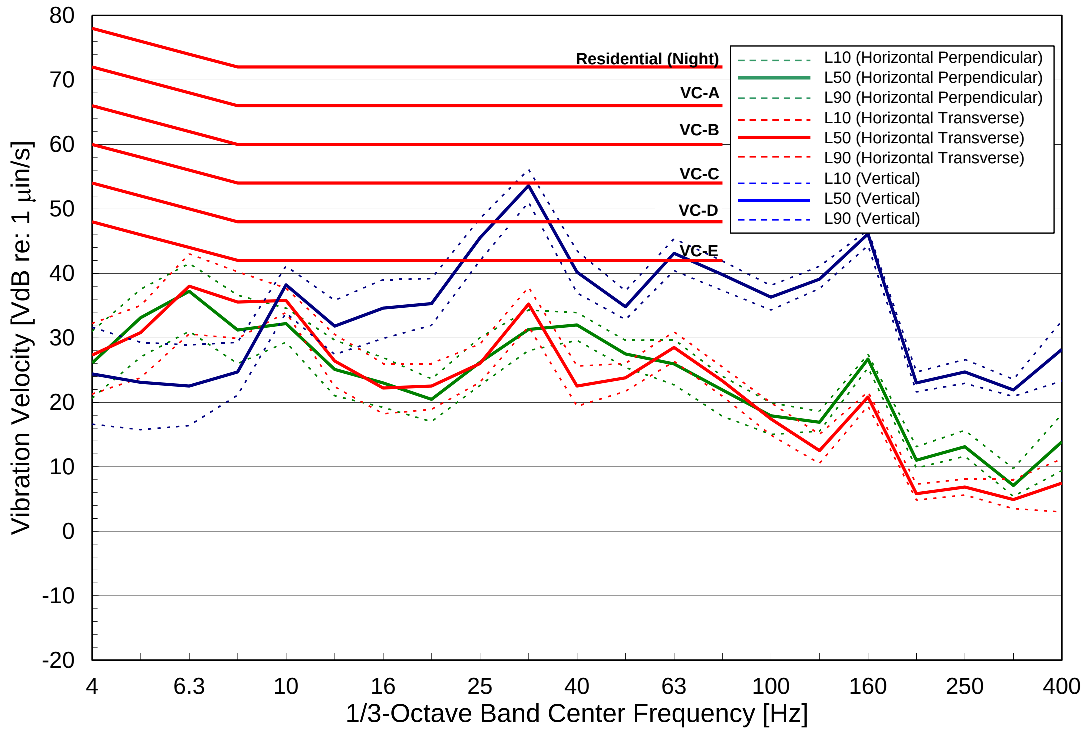


Figure 5
Ambient vibration spectra at Grigg Hall - Room 239: Six-axis alignment system

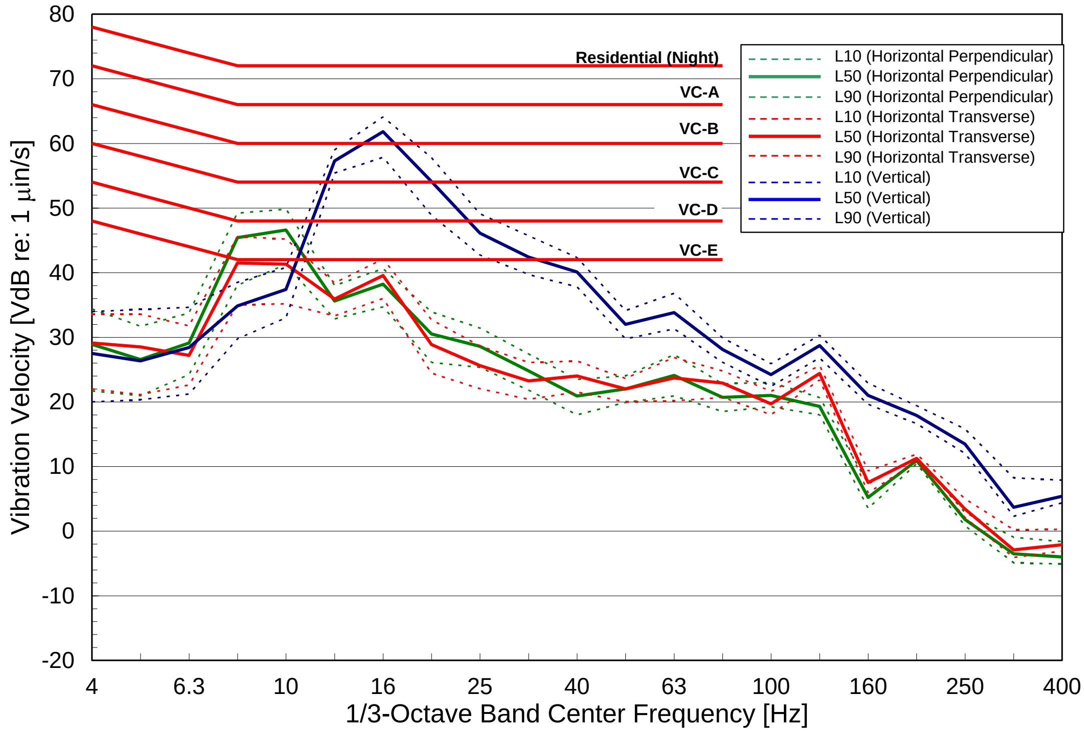


Figure 6
Ambient vibration spectra at Grigg Hall - Room 137: Atomic force microscope

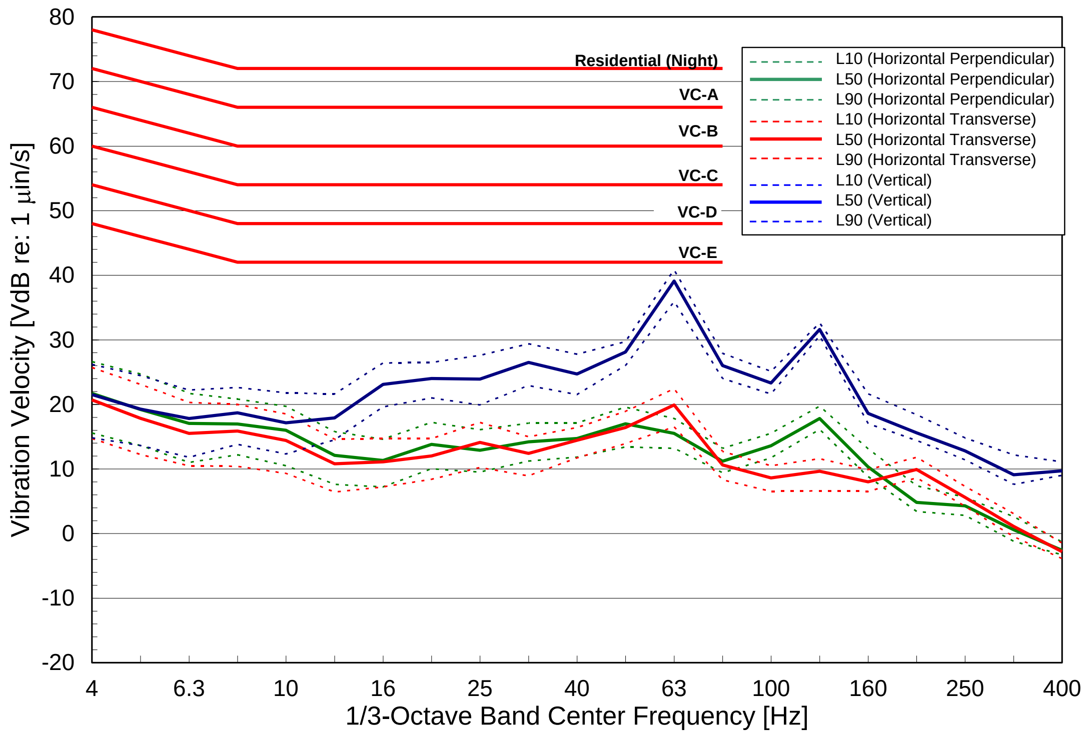


Figure 7
Ambient vibration spectra at Grigg Hall - Room 153: E-beam lithography

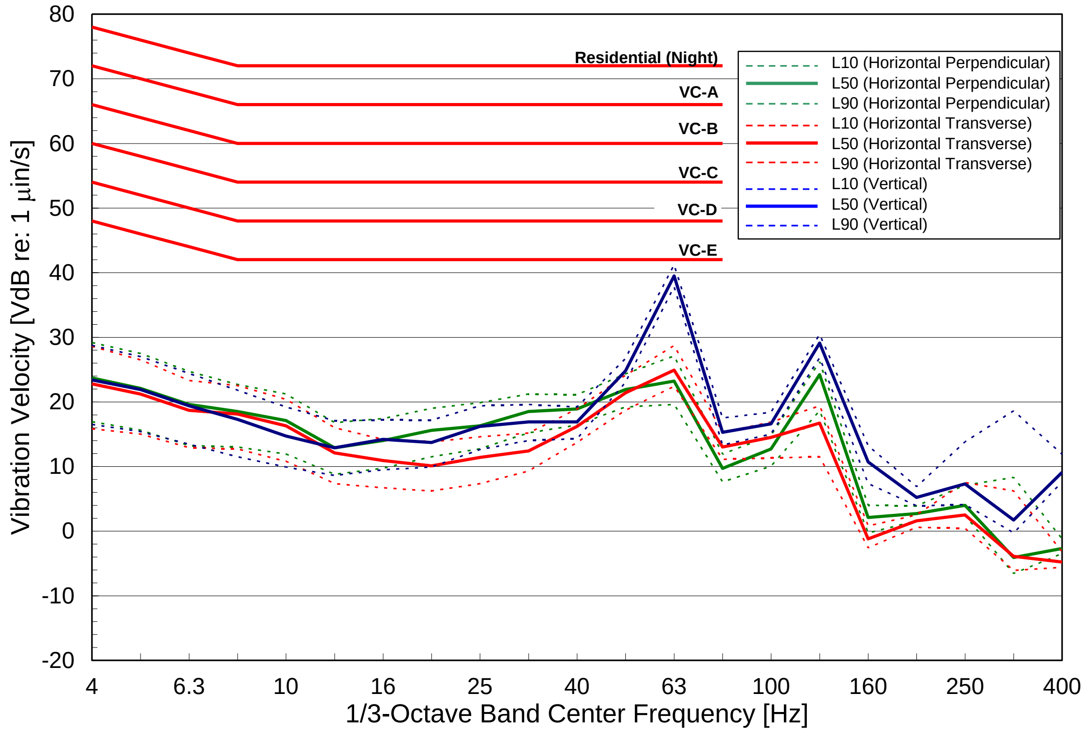


Figure 8
Ambient vibration spectra at Grigg Hall - Room 152: Scanning electron microscope

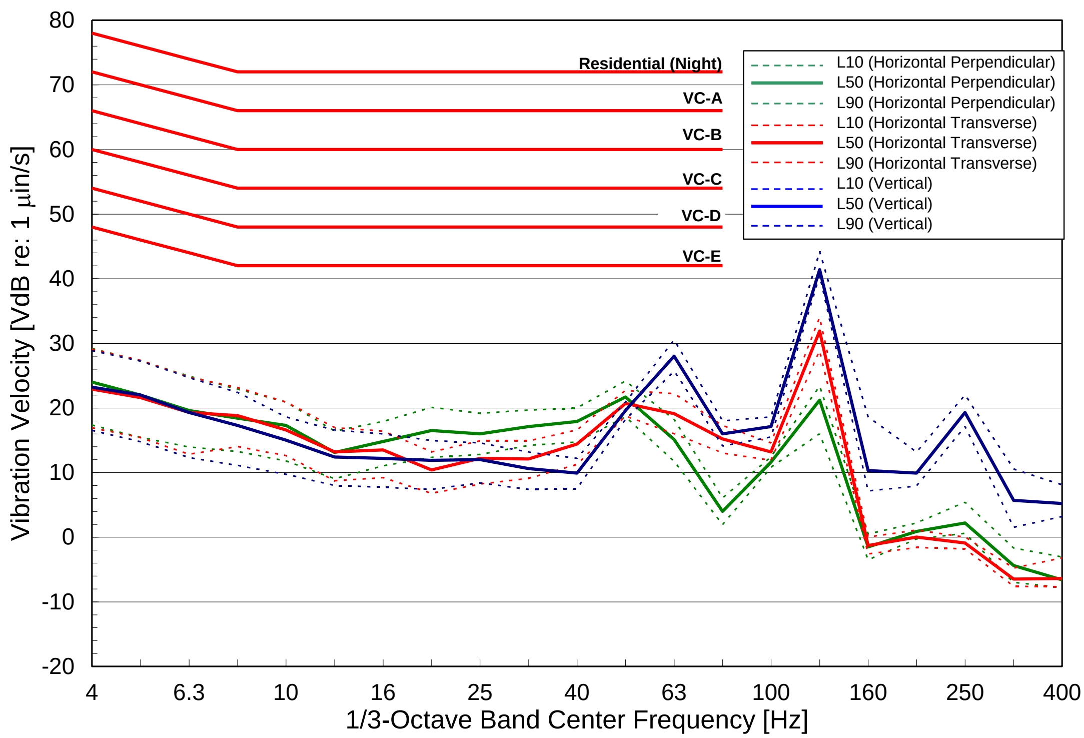
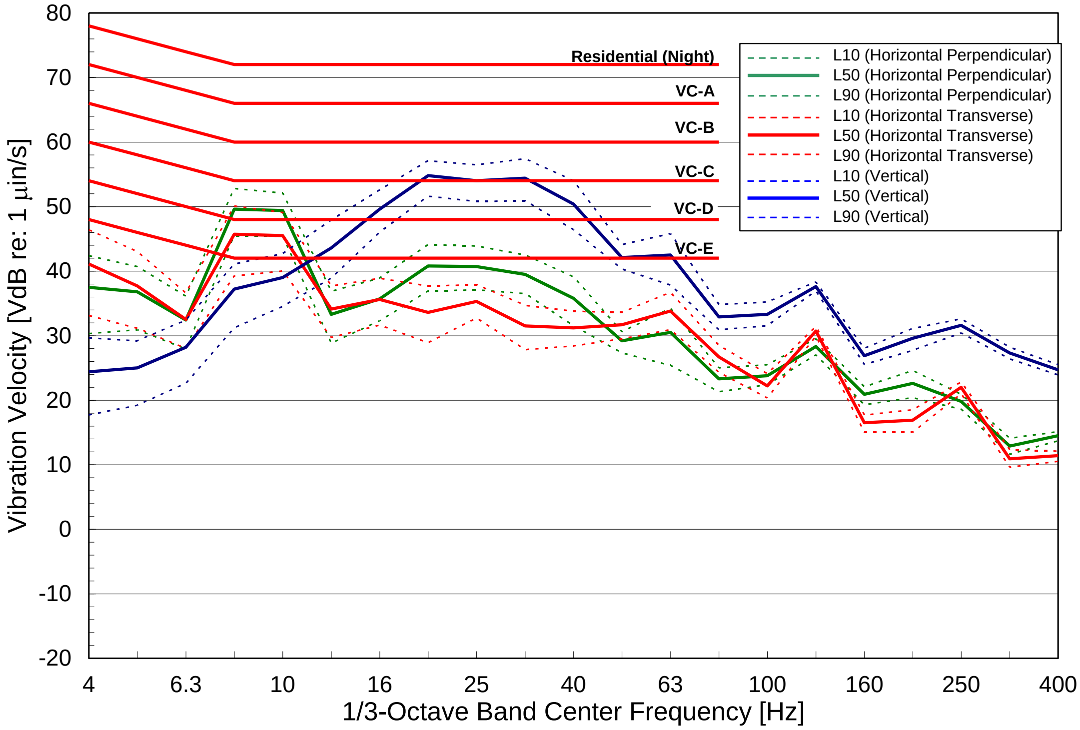


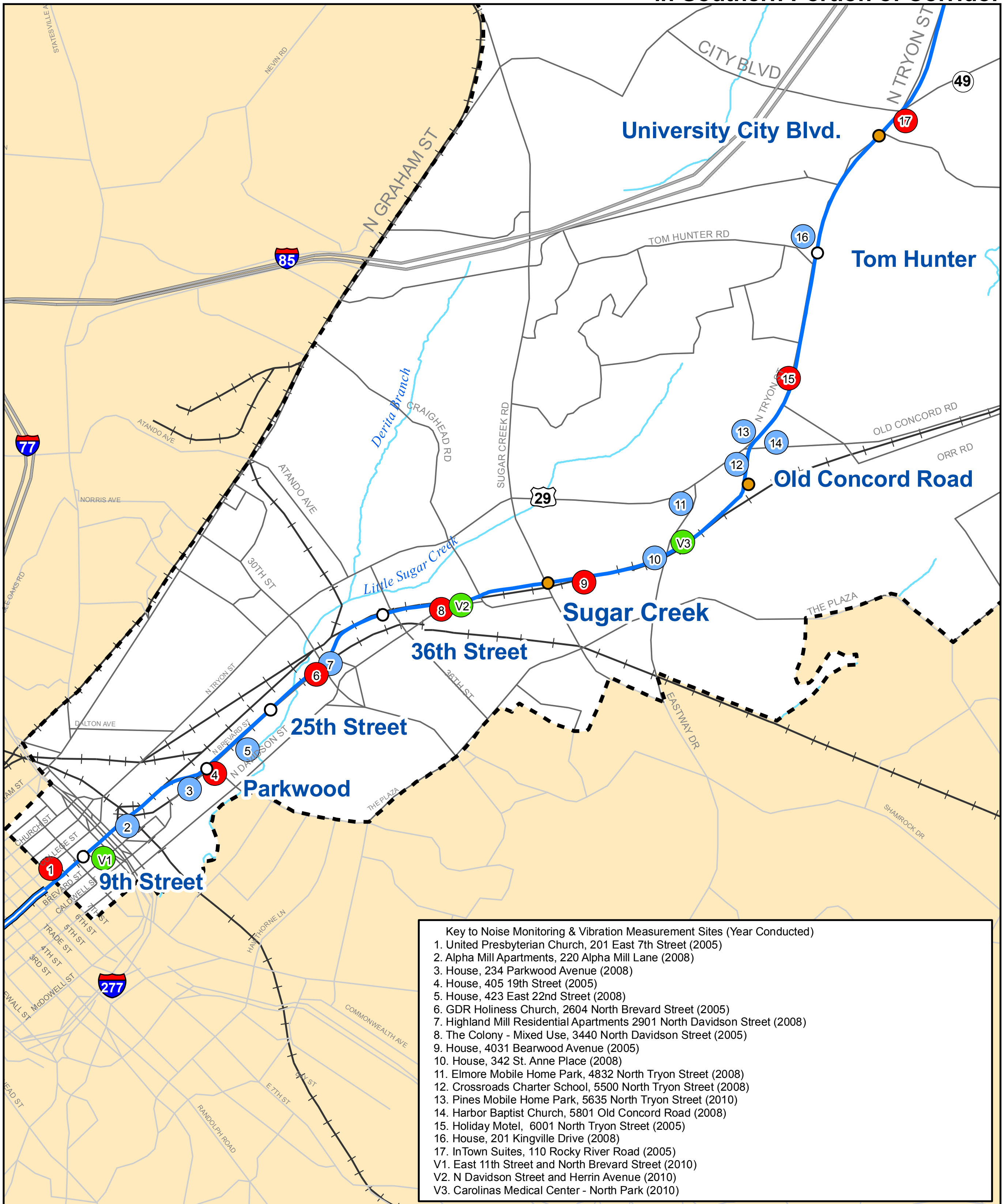
Figure 9
Ambient vibration spectra at Grigg Hall - Room 371: (Clean Room) General lithography, mask aligner system



Appendix E Noise and Vibration Measurement Location Figure

LYNX Rapid Transit Services Blue Line Extension

Figure 1
Noise Monitoring & Vibration Measurement Sites in Southern Portion of Corridor



Key to Noise Monitoring & Vibration Measurement Sites (Year Conducted)

1. United Presbyterian Church, 201 East 7th Street (2005)
2. Alpha Mill Apartments, 220 Alpha Mill Lane (2008)
3. House, 234 Parkwood Avenue (2008)
4. House, 405 19th Street (2005)
5. House, 423 East 22nd Street (2008)
6. GDR Holiness Church, 2604 North Brevard Street (2005)
7. Highland Mill Residential Apartments 2901 North Davidson Street (2008)
8. The Colony - Mixed Use, 3440 North Davidson Street (2005)
9. House, 4031 Bearwood Avenue (2005)
10. House, 342 St. Anne Place (2008)
11. Elmore Mobile Home Park, 4832 North Tryon Street (2008)
12. Crossroads Charter School, 5500 North Tryon Street (2008)
13. Pines Mobile Home Park, 5635 North Tryon Street (2010)
14. Harbor Baptist Church, 5801 Old Concord Road (2008)
15. Holiday Motel, 6001 North Tryon Street (2005)
16. House, 201 Kingville Drive (2008)
17. InTown Suites, 110 Rocky River Road (2005)

V1. East 11th Street and North Brevard Street (2010)
V2. N Davidson Street and Herrin Avenue (2010)
V3. Carolinas Medical Center - North Park (2010)

Legend

- Northeast Corridor Limits
- Light Rail Transit
- Proposed Stations
- Proposed Stations with Park-and-Ride
- LYNX Existing Ligh Rail Tranist
- Highway
- Highway (Future)
- Major Roads
- Railroads
- 2005 Noise Monitoring Sites
- 2008 Noise Monitoring Sites
- 2010 Vibration Measurement Sites

0 0.25 0.5 Mile

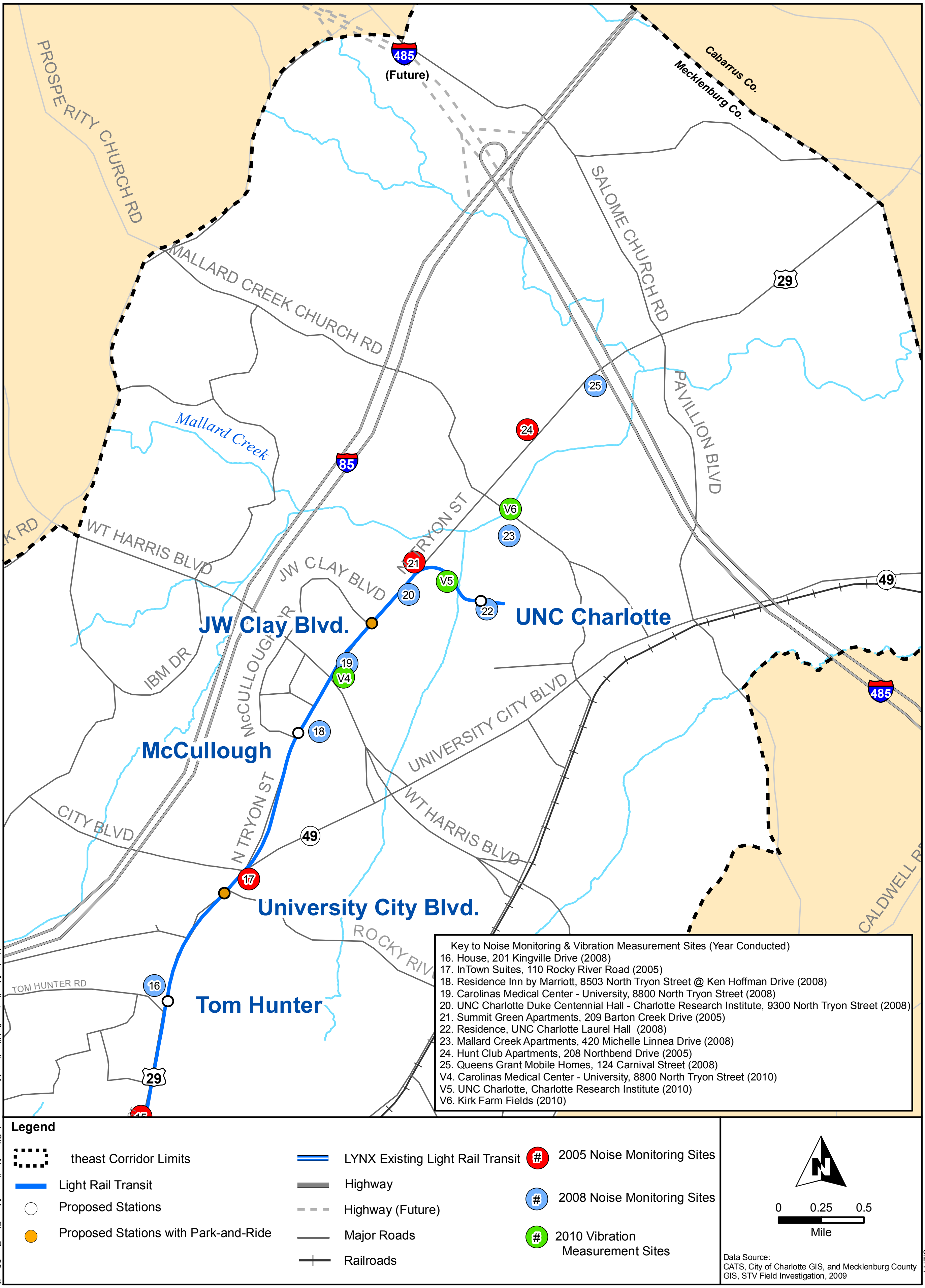
Data Source: CATS, City of Charlotte GIS, and Mecklenburg County GIS, STV Field Investigation, 2009

12.2.10

Nosie_Monitoring_&_Vibration_Measurement_Sites_Northern_Map_Fig_Rev.00.pdf

LYNX Rapid Transit Services Blue Line Extension

Figure 2
Noise Monitoring & Vibration Measurement Sites in Northern Portion of Corridor



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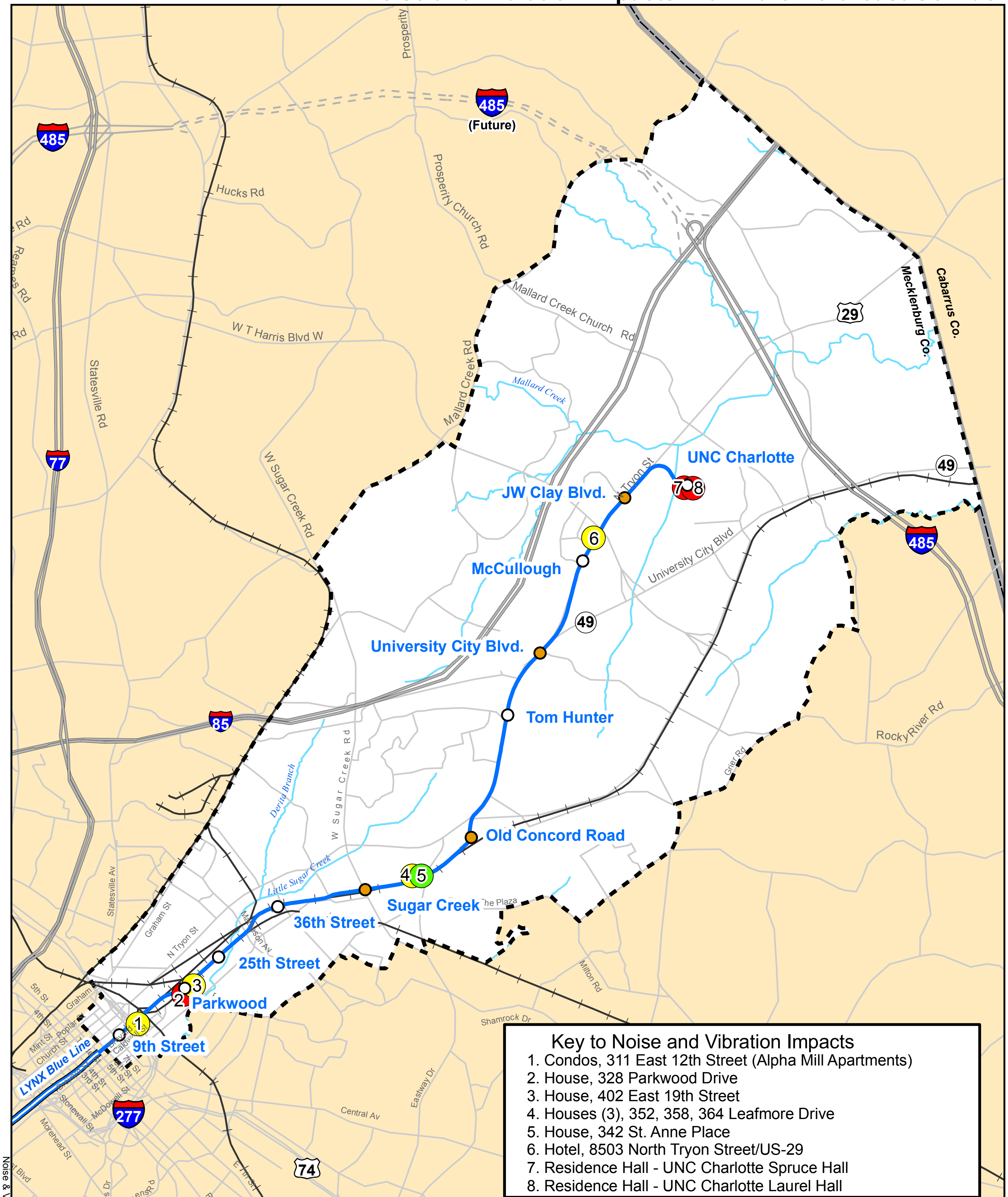
3.2.11

Appendix F Noise and Vibration Impact and Mitigation Location Figures

LYNX Blue Line Extension

Figure 1

Noise and Vibration Impacts within the Northeast Corridor



Key to Noise and Vibration Impacts

1. Condos, 311 East 12th Street (Alpha Mill Apartments)
2. House, 328 Parkwood Drive
3. House, 402 East 19th Street
4. Houses (3), 352, 358, 364 Leafmore Drive
5. House, 342 St. Anne Place
6. Hotel, 8503 North Tryon Street/US-29
7. Residence Hall - UNC Charlotte Spruce Hall
8. Residence Hall - UNC Charlotte Laurel Hall

Legend

- Northeast Corridor Limits
- Proposed Light Rail Alignment
- Proposed Stations
- Proposed Stations with Park-and-Ride
- LYNX Existing Light Rail Transit
- Highway
- Major Roads
- Highway (Future)
- Streams
- Railroads
- County Line
- Moderate Noise Impact
- Severe Noise Impact
- Vibration Impact

0 0.5 1
Mile

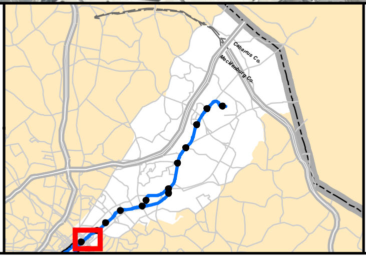
Data Source:
CATS, City of Charlotte GIS, and Mecklenburg County GIS, STV Field Investigation, 2009

LYNX Rapid Transit Services Blue Line Extension

Figure 2
Potential Noise Impacts

Legend

- Proposed Light Rail Alternative
- Proposed Track Crossover
- Design Option
- Proposed Retaining Walls
- Proposed ROW
- Proposed Station Platform
- Proposed Substation
- Proposed Signal Houses
- Proposed Park-and-Ride Facilities
- Proposed Structures
- Roads
- Streams
- Railroads
- Moderate Noise Impacts
- Severe Noise Impacts
- Rail Lubrication System
- Noise Barrier
- Sound Insulation Improvements



N

0 75 150 300 Feet

Feet

1 inch = 300 feet

Data Source: Charlotte Area Transit System, STV/RWA, Mecklenburg County GIS Aerial (2007)

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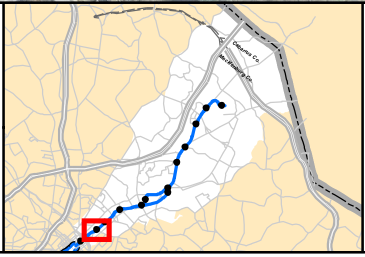
March 28, 2011

Blue Line Extension

Figure 3
Potential Noise Impacts

Legend

- Proposed Light Rail Alternative
- Proposed Track Crossover
- Design Option
- Proposed Retaining Walls
- Proposed ROW
- Proposed Station Platform
- Proposed Substation
- Proposed Signal Houses
- Proposed Park-and-Ride Facilities
- Proposed Structures
- Roads
- Streams
- Railroads
- Moderate Noise Impacts
- Severe Noise Impacts
- Rail Lubrication System
- Noise Barrier
- Sound Insulation Improvements



0 75 150 300 Feet

Feet

1 inch = 300 feet

Data Source: Charlotte Area Transit System, STV/RWA, Mecklenburg County GIS Aerial (2007)

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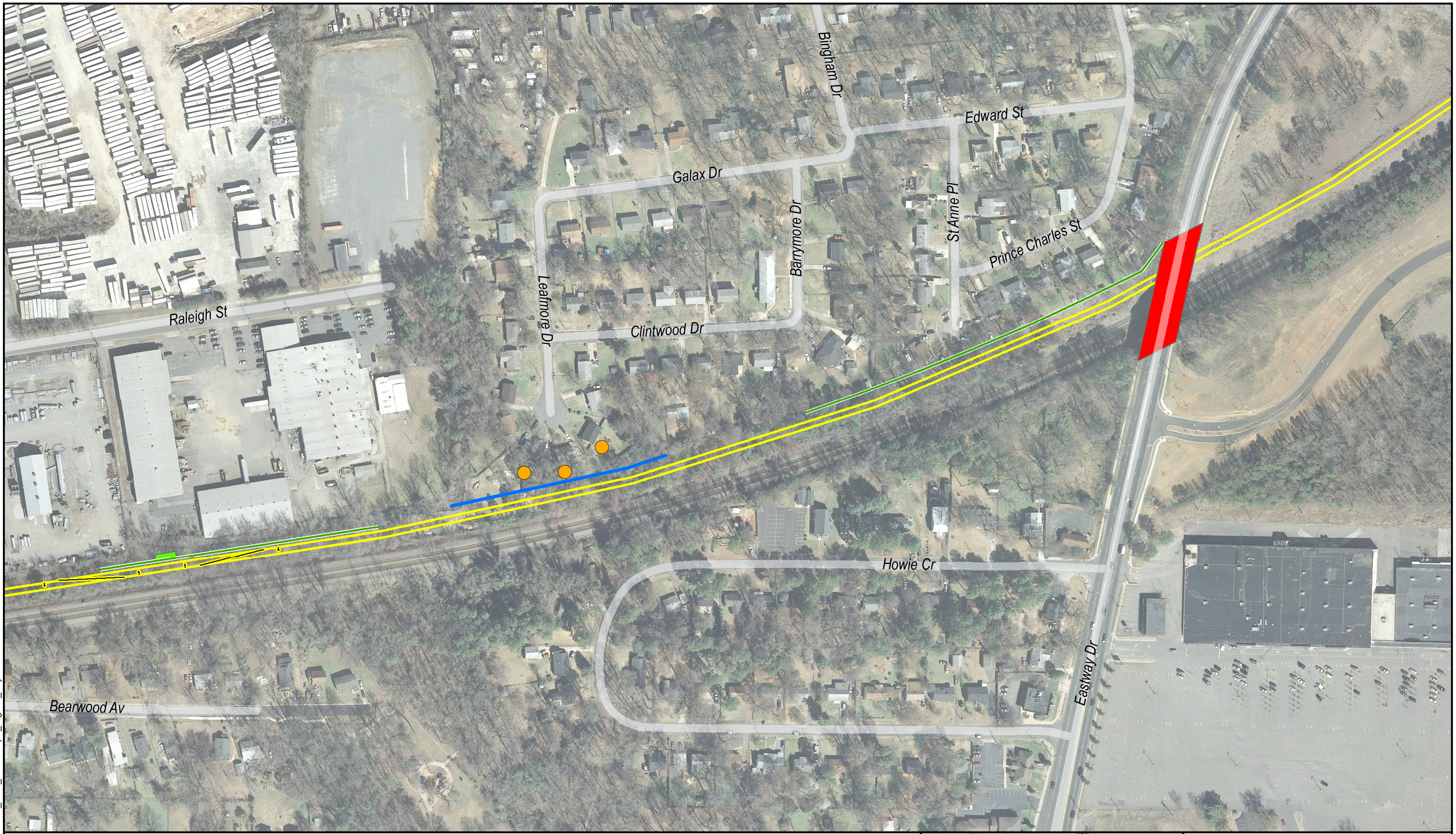
March 28, 2011

LYNX RAPID TRANSIT SERVICES Blue Line Extension

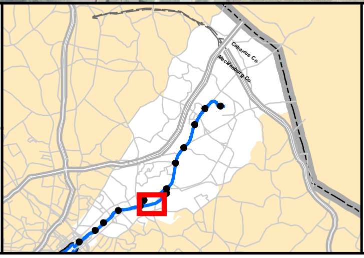
Figure 4
Potential Noise Impacts



Legend

Proposed Light Rail Alternative	Proposed Station Platform	Roads
Proposed Track Crossover	Proposed Substation	Streams
Design Option	Proposed Signal Houses	Railroads
Proposed Retaining Walls	Proposed Park-and-Ride Facilities	Noise Barrier
Proposed ROW	Proposed Structures	Sound Insulation Improvements

Moderate Noise Impacts
Severe Noise Impacts
Rail Lubrication System



N

0 75 150 300 Feet

Feet

1 inch = 300 feet

Data Source: Charlotte Area Transit System, STV/RWA, Mecklenburg County GIS Aerial (2007)

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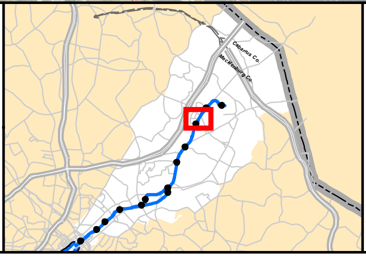
March 28, 2011

LYNX Rapid Transit Services Blue Line Extension

Figure 5
Potential Noise Impacts

Legend

Proposed Light Rail Alternative	Proposed Station Platform	Roads	Moderate Noise Impacts
Proposed Track Crossover	Proposed Substation	Streams	Severe Noise Impacts
Design Option	Proposed Signal Houses	Railroads	Rail Lubrication System
Proposed Retaining Walls	Proposed Park-and-Ride Facilities		Noise Barrier
Proposed ROW	Proposed Structures		Sound Insulation Improvements



N

0 75 150 300 Feet

Feet

1 inch = 300 feet

Data Source: Charlotte Area Transit System, STV/RWA, Mecklenburg County GIS Aerial (2007)

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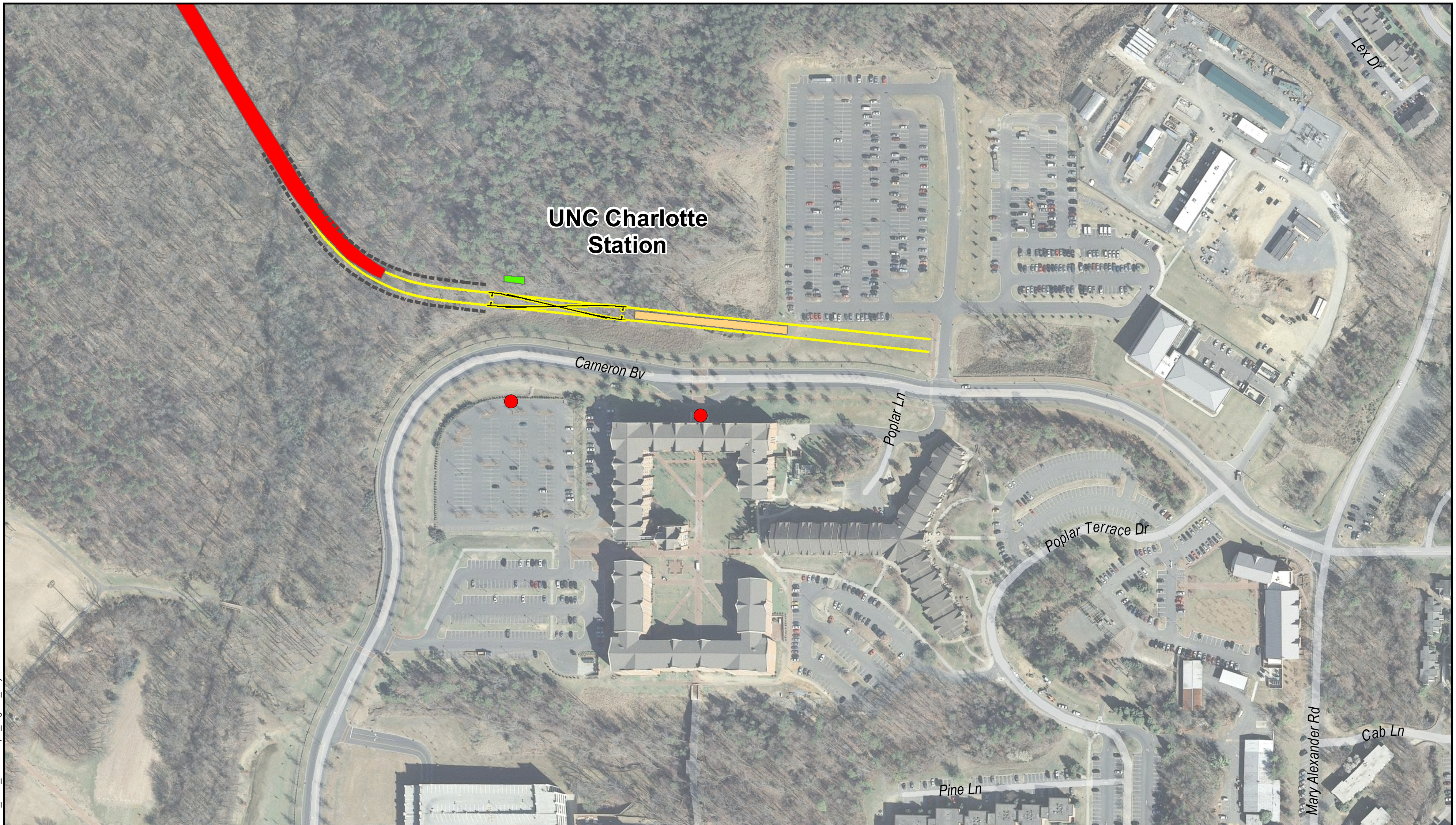
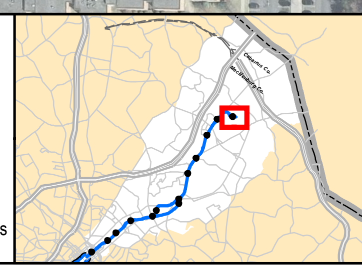
March 28, 2011

Figure 6
Potential Noise Impacts



Legend

Proposed Light Rail Alternative	Proposed Station Platform	Roads	Moderate Noise Impacts
Proposed Track Crossover	Proposed Substation	Streams	Severe Noise Impacts
Design Option	Proposed Signal Houses	Railroads	Rail Lubrication System
Proposed Retaining Walls	Proposed Park-and-Ride Facilities		Noise Barrier
Proposed ROW	Proposed Structures		Sound Insulation Improvements



0 75 150 300 Feet

Feet

1 inch = 300 feet

Data Source: Charlotte Area Transit System, STV/RWA, Mecklenburg County GIS Aerial (2007)

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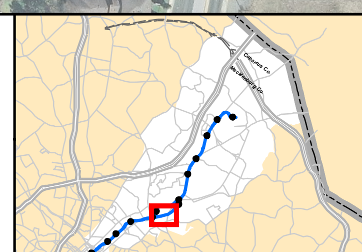
March 28, 2011

LYNX RAPID TRANSIT SERVICES Blue Line Extension

Figure 7
Potential Vibration Impacts

Legend

- Proposed Light Rail Alternative
- Proposed Track Crossover
- Design Option
- Proposed Retaining Walls
- Proposed ROW
- Proposed Station Platform
- Proposed Substation
- Proposed Signal Houses
- Proposed Park-and-Ride Facilities
- Proposed Structures
- Roads
- Streams
- Railroads
- Vibration Impacts
- Track Vibration Isolation



N

0 75 150 300 Feet

Feet

1 inch = 300 feet

Data Source: Charlotte Area Transit System, STV/RWA, Mecklenburg County GIS Aerial (2007)

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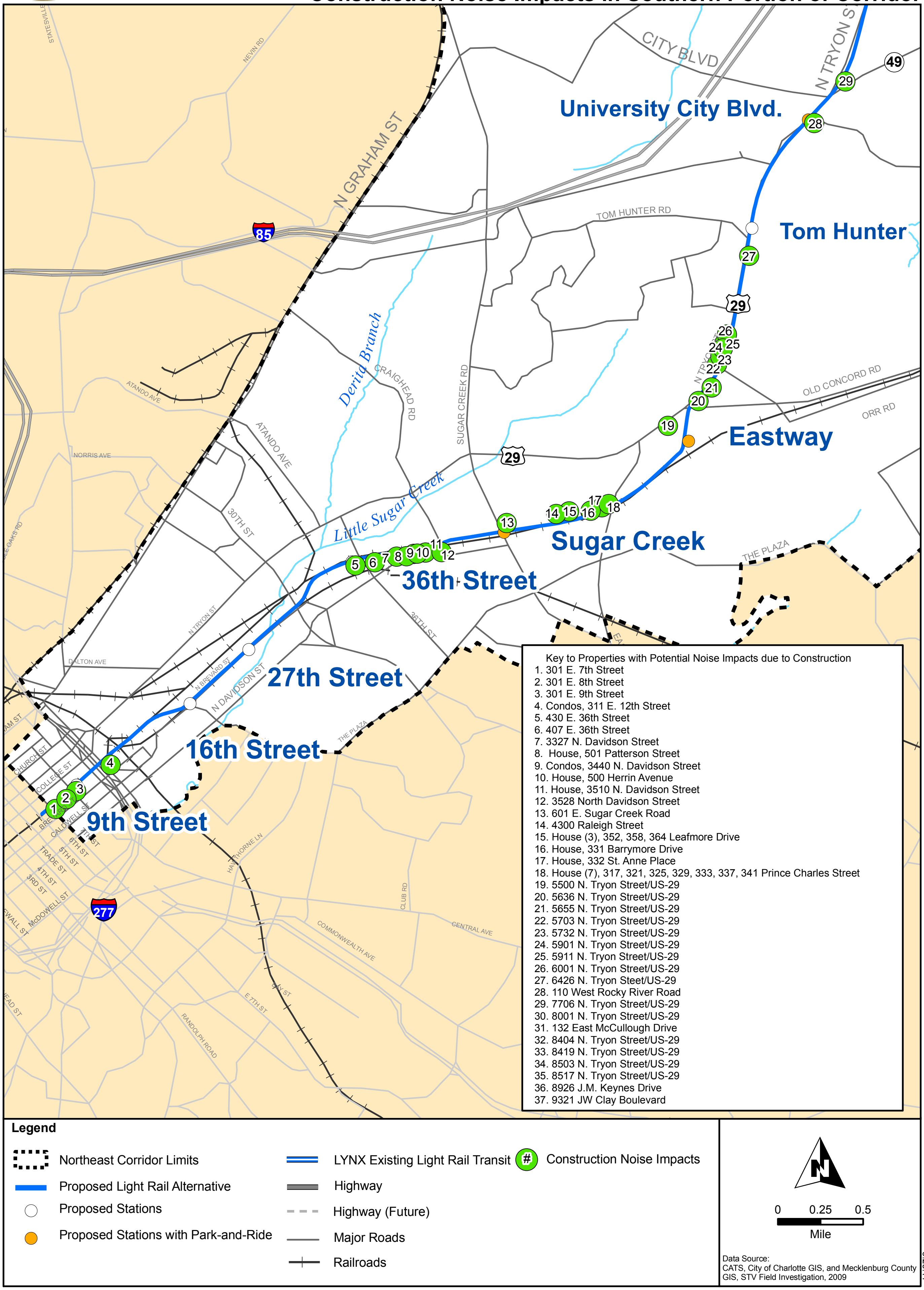
March 28, 2011

LYNX Rapid Transit Services Blue Line Extension

Figure 8a
Construction Noise Impacts in Southern Portion of Corridor



Construction Noise_Impacts_Southern_Map_Rev00Draft02_05/25/11.pdf

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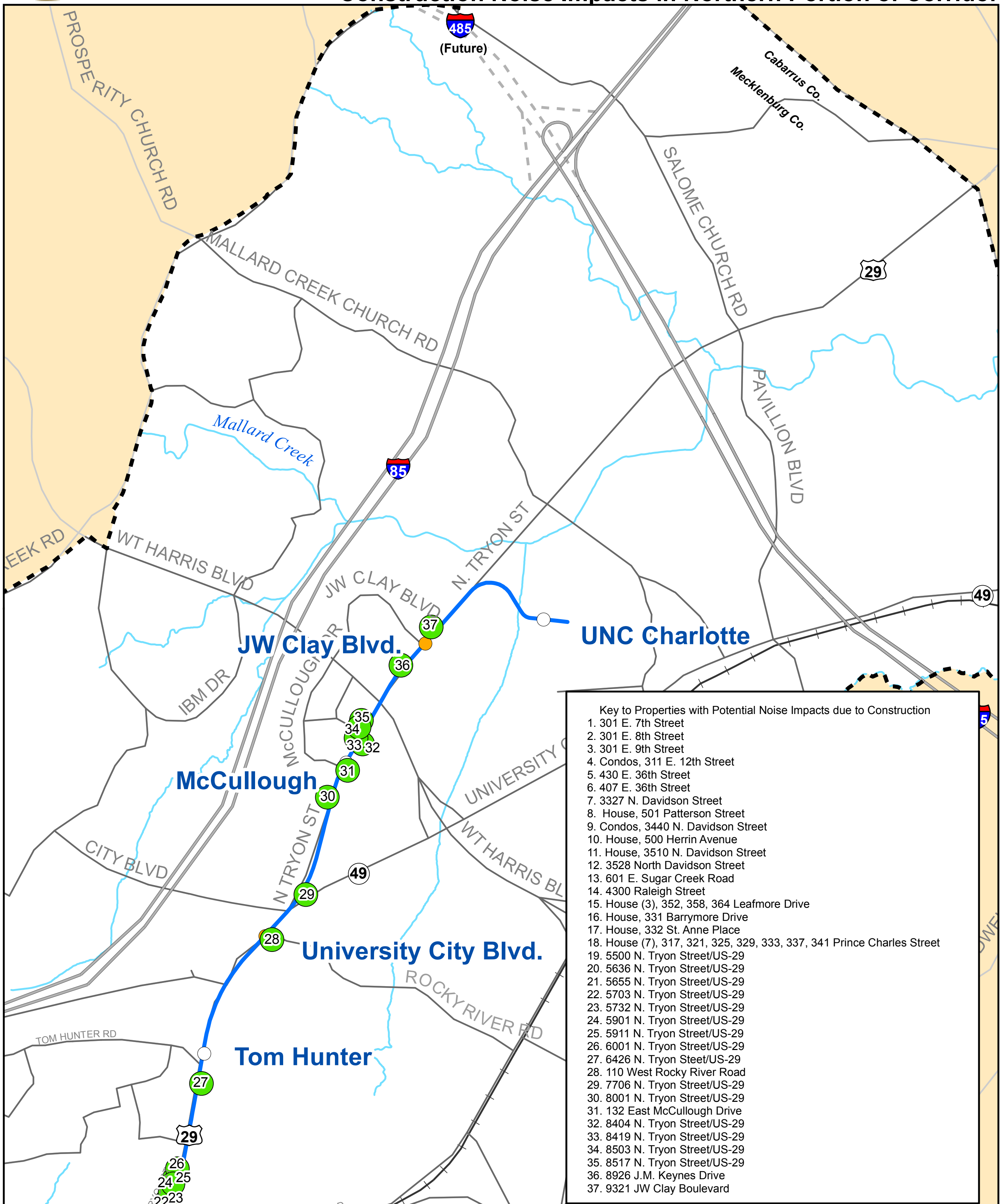
LYNX Blue Line Extension

Figure 8b

Construction Noise Impacts in Northern Portion of Corridor



Key to Properties with Potential Noise Impacts due to Construction

1. 301 E. 7th Street
2. 301 E. 8th Street
3. 301 E. 9th Street
4. Condos, 311 E. 12th Street
5. 430 E. 36th Street
6. 407 E. 36th Street
7. 3327 N. Davidson Street
8. House, 501 Patterson Street
9. Condos, 3440 N. Davidson Street
10. House, 500 Herrin Avenue
11. House, 3510 N. Davidson Street
12. 3528 North Davidson Street
13. 601 E. Sugar Creek Road
14. 4300 Raleigh Street
15. House (3), 352, 358, 364 Leafmore Drive
16. House, 331 Barrymore Drive
17. House, 332 St. Anne Place
18. House (7), 317, 321, 325, 329, 333, 337, 341 Prince Charles Street
19. 5500 N. Tryon Street/US-29
20. 5636 N. Tryon Street/US-29
21. 5655 N. Tryon Street/US-29
22. 5703 N. Tryon Street/US-29
23. 5732 N. Tryon Street/US-29
24. 5901 N. Tryon Street/US-29
25. 5911 N. Tryon Street/US-29
26. 6001 N. Tryon Street/US-29
27. 6426 N. Tryon Steet/US-29
28. 110 West Rocky River Road
29. 7706 N. Tryon Street/US-29
30. 8001 N. Tryon Street/US-29
31. 132 East McCullough Drive
32. 8404 N. Tryon Street/US-29
33. 8419 N. Tryon Street/US-29
34. 8503 N. Tryon Street/US-29
35. 8517 N. Tryon Street/US-29
36. 8926 J.M. Keynes Drive
37. 9321 JW Clay Boulevard

Legend

- Northeast Corridor Limits
- Proposed Light Rail Alternative
- Proposed Stations
- Proposed Stations with Park-and-Ride
- LYNX Existing Light Rail Transit
- Highway
- Highway (Future)
- Major Roads
- Railroads
- # Construction Noise Impacts

0 0.25 0.5 Mile

Data Source:
CATS, City of Charlotte GIS, and Mecklenburg County GIS, STV Field Investigation, 2009

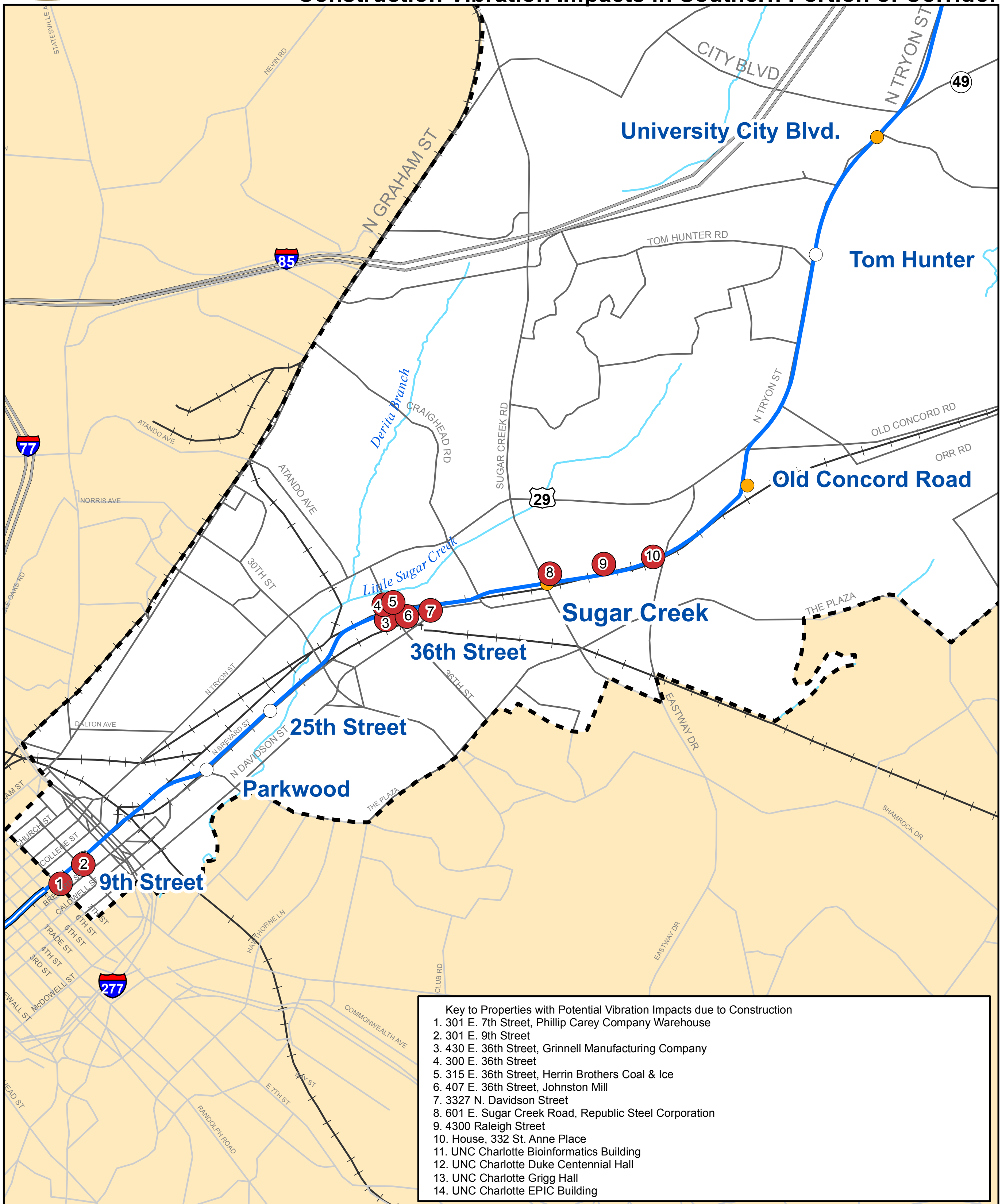
Construction Noise_Impactss_Northern_Map_Rev00Draft02_05/25/11.pdf

5.25.11

LYNX Blue Line Extension

Figure 9a

Construction Vibration Impacts in Southern Portion of Corridor



Key to Properties with Potential Vibration Impacts due to Construction

1. 301 E. 7th Street, Phillip Carey Company Warehouse
2. 301 E. 9th Street
3. 430 E. 36th Street, Grinnell Manufacturing Company
4. 300 E. 36th Street
5. 315 E. 36th Street, Herrin Brothers Coal & Ice
6. 407 E. 36th Street, Johnston Mill
7. 3327 N. Davidson Street
8. 601 E. Sugar Creek Road, Republic Steel Corporation
9. 4300 Raleigh Street
10. House, 332 St. Anne Place
11. UNC Charlotte Bioinformatics Building
12. UNC Charlotte Duke Centennial Hall
13. UNC Charlotte Grigg Hall
14. UNC Charlotte EPIC Building

Legend

- Northeast Corridor Limits
- Proposed Light Rail Alternative
- Proposed Stations
- Proposed Stations with Park-and-Ride
- LYNX Existing Ligh Rail Tranist
- Highway
- Highway (Future)
- Major Roads
- Railroads
- # Construction Vibration Impacts

N

0 0.25 0.5
Mile

Data Source:
CATS, City of Charlotte GIS, and Mecklenburg County GIS, STV Field Investigation, 2009

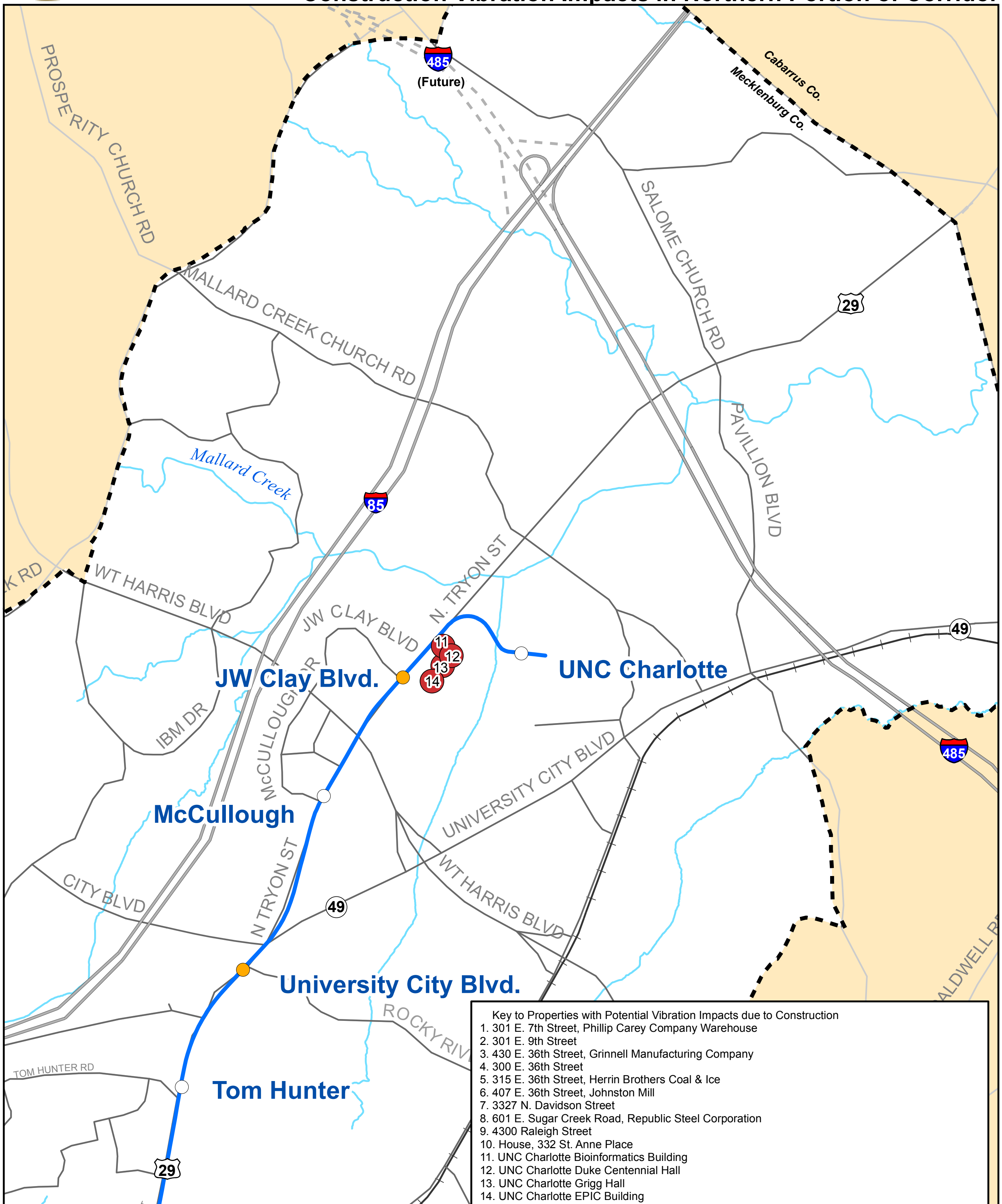
5.25.11

Construction Vibration_Impactss_Southernn_Map_Rev00Draft02_05/25/11.pdf

LYNX Blue Line Extension

Figure 9b

Construction Vibration Impacts in Northern Portion of Corridor



Key to Properties with Potential Vibration Impacts due to Construction
1. 301 E. 7th Street, Phillip Carey Company Warehouse
2. 301 E. 9th Street
3. 430 E. 36th Street, Grinnell Manufacturing Company
4. 300 E. 36th Street
5. 315 E. 36th Street, Herrin Brothers Coal & Ice
6. 407 E. 36th Street, Johnston Mill
7. 3327 N. Davidson Street
8. 601 E. Sugar Creek Road, Republic Steel Corporation
9. 4300 Raleigh Street
10. House, 332 St. Anne Place
11. UNC Charlotte Bioinformatics Building
12. UNC Charlotte Duke Centennial Hall
13. UNC Charlotte Grigg Hall
14. UNC Charlotte EPIC Building

Legend

- Northeast Corridor Limits
- Proposed Light Rail Alternative
- Proposed Stations
- Proposed Stations with Park-and-Ride
- LYNX Existing Light Rail Transit
- Highway
- Highway (Future)
- Major Roads
- Railroads
- Construction Vibration Impacts

N

0 0.25 0.5
Mile

Data Source:
CATS, City of Charlotte GIS, and Mecklenburg County GIS, STV Field Investigation, 2009

Construction Vibration_Impactss_Northern_Map_Rev00Draft02_05/25/11.pdf

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Appendix G Noise Projections at All Receptors Prior to Mitigation

Noise Sensitive Receptor Location	Station Number	Distance to Near Track Centerline (feet)	Speed of LRV (mph)	Existing Noise Level (Ldn)	Project Noise Impact Criteria (Ldn)		Project Noise Level (Ldn)	Future Noise Level (Ldn)	Additional Noise Sources
					Mod.	Sev.			
201 East 7th Street First United Presbyterian Church	1005+00	330	15	63.0 h	64.6	70.0	41.8 h	63.0	f
320 East 9th Street New Construction High Rise	1012+00	250	15	61.0	58.4	63.9	49.8	61.3	f
618 North College Street Charlotte Government Building	1015+00	150	15	63.0 h	64.6	70.0	50.7 h	63.2	f, g
311 East 12th St Alpha Mill Apartments	1026+00	90	45	71.0	65.0	70.2	67.0	72.5	b, f
234 Parkwood Avenue (SFR)	1050+00	300	30	72.7	65.0	71.4	57.9	72.8	a, f
328 Parkwood Avenue (SFR)	1060+00	100	30	69.0	63.6	68.8	72.3	74.0	c
402 East 19th Street (SFR)	1060+00	150	15	69.0	63.6	68.8	68.2	71.6	c, g
405 East 19th Street (SFR)	1060+00	230	15	64.5	60.4	65.8	53.9	64.8	g
2901 North Davidson Street Highland Mill Apartments	1110+00	330	35	63.1	59.6	65.1	52.6	63.5	
501 Patterson Street (SFR)	1145+00	85	45	72.3	65.0	71.1	64.2	72.9	
500 Herrin Avenue (SFR)	1145+00	100	45	69.0	63.6	68.8	63.1	70.0	
3400 North Davidson Street The Colony	1145+00	100	45	69.0	63.6	68.8	63.1	70.0	
3510 North Davidson Street (SFR)	1148+00	100	45	70.5	64.7	69.8	63.1	71.2	
3528 North Davidson Street Renaissance Apartments	1152+00	120	35	69.0	63.6	68.8	59.6	69.5	
3905, 3903, 3913 Bearwood Avenue (SFR)	1176+00	150	20	75.2	65.0	73.3	53.2	75.2	e
3927, 3929 Bearwood Avenue (SFR)	1178+00	130	30	76.9	65.0	74.7	57.7	77.0	
3931, 4001, 4009 Bearwood Avenue (SFR)	1180+00	150	35	75.2	65.0	73.3	58.1	75.3	
4025, 4027, 4029 Bearwood Avenue (SFR)	1182+00	140	42	76.0	65.0	74.0	63.2	76.2	a
4031, 4035, 4115 Bearwood Avenue (SFR)	1185+00	180	44	73.2	65.0	71.8	64.8	73.8	a
4119, 4125 Bearwood Avenue (SFR)	1187+00	230	45	70.9	65.0	70.1	63.3	71.6	a
4135, 4131, 4141 Bearwood Avenue (SFR)	1190+00	250	55	70.9	65.0	70.1	64.5	71.8	a
4201 Howie Circle (SFR)	1194+00	200	55	70.9	65.0	70.1	60.0	71.2	
358 Leafmore Drive (SFR)	1195+00	65	55	70.4	64.7	69.8	67.7	72.3	

Noise Sensitive Receptor Location	Station Number	Distance to Near Track Centerline (feet)	Speed of LRV (mph)	Existing Noise Level (Ldn)	Project Noise Impact Criteria (Ldn)		Project Noise Level (Ldn)	Future Noise Level (Ldn)	Additional Noise Sources
					Mod.	Sev.			
352 and 364 Leafmore Drive(SFR)	1195+00	80	55	69.8	64.1	69.3	66.3	71.4	
346, 372 Leafmore Drive (SFR)	1195+00	150	55	67.4	62.5	67.7	59.0	68.0	
4215 Howie Circle (SFR)	1195+00	125	55	76.2	65.0	74.1	63.3	76.4	
4235 Howie Circle (SFR)	1197+00	140	55	74.7	65.0	73.0	62.5	75.0	
4301 Howie Circle Vietnamese Baptist Church	1198+00	115	55	64.8 h	65.6	71.0	57.7 h	65.5	
4914, 4922, 4928 Clintwood Drive (SFR)	1199+00	180	55	66.6	61.9	67.2	60.8	67.6	
4934, 4942, 4948 Clintwood Drive (SFR)	1200+00	150	55	67.9	62.7	68.0	62.0	68.9	
4307, 4315, 4321 Howie Circle (SFR)	1201+00	200	55	70.9	65.0	70.1	60.0	71.2	
331 Barrymore Drive (SFR)	1201+00	120	55	69.0	63.6	68.8	63.5	70.1	
332 St. Anne Place (SFR)	1204+00	45	55	71.4	72.3 i	74.0 i	n/a	71.1 i	
4329, 4337 Howie Circle (SFR)	1205+00	280	55	67.9	62.7	68.0	57.7	68.3	
438 Eastway Drive (SFR)	1205+00	350	55	66.0	61.5	66.8	56.1	66.5	
341, 337, 333, 329, 325, 321 Prince Charles Street (SFR)	1207+00	100	55	69.6	64.0	69.1	60.9	70.1	
317 Prince Charles Street (SFR)	1208+00	120	55	68.3	63.1	68.3	56.7	68.6	
251 Eastway Drive Carolinas Medical Center - Northpark	1220+00	80	55	62.5 h	64.2	69.7	63.9 h	66.3	d
5500 North Tryon Street/US-29 Crossroads Charter High School	2002+00	185	25	59.3 h	62.4	68.0	53.8 h	60.4	b, e, f, g
5635 North Tryon Street/US-29 Pines Mobile Homes	2009+00	200	35	61.5	58.6	64.2	53.1	62.1	
5911 North Tryon Street/US-29 Star Motel	2028+00	70	35	70.0	64.4	69.5	63.3	70.8	
6001 North Tryon Street/US-29 Holiday Motel	2031+00	60	35	70.0	64.4	69.5	64.3	71.0	
6442 North Tryon Street/US-29 Fairyland Learning Center	2063+00	170	25	66.9 h	67.0	72.3	48.1 h	66.9	
6919 North Tryon Street/US-29 (SFR)	2088+00	350	45	62.2	59.0	64.5	54.3	62.8	
6811 Kemp St (SFR)	2088+00	400	45	61.3	58.5	64.0	50.4	61.6	
110 West Rocky River Rd Intown Suites Hotel	3004+00	220	40	62.0	63.7 i	66.4 i	n/a	61.9 i	d

Noise Sensitive Receptor Location	Station Number	Distance to Near Track Centerline (feet)	Speed of LRV (mph)	Existing Noise Level (Ldn)	Project Noise Impact Criteria (Ldn)		Project Noise Level (Ldn)	Future Noise Level (Ldn)	Additional Noise Sources
					Mod.	Sev.			
7706 North Tryon Street/US-29 Intown Suites Hotel	3020+00	140	40	63.9	60.1	65.5	59.7	65.3	
132 East McCullough Dr Microtel Inn	3038+00	120	29	69.1	63.7	68.9	62.1	69.9	b, f
8419 North Tryon Street/US-29 Hampton Inn	3059+00	160	32	68.1	63.0	68.2	62.2	69.1	b, f
8503 North Tryon Street/US-29 Marriott Residence Inn	3065+00	90	45	71.4	65.0	70.4	66.9	72.7	b, f
8800 North Tryon Street/US-29 Carolinas Medical Center University	3075+00	240	45	64.6	60.6	66.0	59.9	65.9	b, f
UNC Charlotte Epic Building	3090+00	1000	45	38.4 h	56.6	62.7	43.7 h	44.8	a
UNC Charlotte Bioinformatics Building	3100+00	200	45	65.3 h	66.0	71.4	52.3 h	65.5	
UNC Charlotte| Grigg Hall	3100+00	500	45	65.3 h	66.0	71.4	45.4 h	65.3	
UNCC Charlotte Duke Centennial Hall	3100+00	500	45	65.3 h	66.0	71.4	45.4 h	65.3	
9303 Kitansett Drive Summit Green	3109+00	150	35	62.0	58.9	64.5	47.5	62.2	
North Tryon Street/US-29. CMF	3115+00	90	45	70.0	64.4	69.5	63.8	70.9	
UNC Charlotte Spruce Hall	3135+00	204	15	62.1	59.0	64.5	72.6	73.0	a, c, d, g
UNC Charlotte Laurel Hall	3138+00	216	15	62.1	59.0	64.5	67.7	68.8	a, c, d, g
UNC Charlotte Witherspoon Hall	3143+00	216	15	62.1	59.0	64.5	54.3	62.8	g

a Increased noise due to special trackwork included in noise projections.
b Horn noise (low horn) included in noise projections.
c Wheel squeal included in noise projections.
d Traction power sub-station included in noise projections.
e Park and ride included in noise projections.
f Crossing bells included in noise projections.
g Noise projections include contributions from accelerating and decelerating trains in/out of station.
h Noise projections for institutional land use; peak-transit hour Leq
i Impact criteria are for future noise conditions.
(SFR) Single-family residence

Appendix H Vibration Projections at All Receptors Prior to Mitigation

Vibration Sensitive Receptor Location	Station Number	Distance to Near Track Centerline (feet)	Train Speed (mph)	Maximum Vibration Velocity in any 1/3-octave band from 4 to 80 Hz (VdB re: 1 μ-in/sec)	Projections Based on Vibration Test Site
201 East 7th Street First United Presbyterian Church	1005+00	330	15	31	Site 1
320 East 9th Street New Construction High Rise	1012+00	250	15	31	Site 1
618 North College Street Charlotte Government Building	1015+00	150	15	32	Site 1
311 East 12th Street Alpha Mill Apartments	1026+00	90	45	48	Site 1
234 Parkwood Avenue (SFR)	1050+00	300	30	58 a	Site 2
328 Parkwood Avenue (SFR)	1060+00	100	30	59 a	Site 2
402 East 19th Street (SFR)	1060+00	150	15	51	Site 2
405 East 19th Street (SFR)	1060+00	230	15	44	Site 2
2901 North Davidson Street Highland Mill Apartments	1110+00	330	35	49	Site 2
501 Patterson Street (SFR)	1145+00	85	45	60	Site 2
500 Herrin Avenue (SFR)	1145+00	100	45	59	Site 2
3400 North Davidson Street The Colony	1145+00	100	45	59	Site 2
3510 North Davidson Street (SFR)	1148+00	100	45	59	Site 2
Renaissance Apartments	1152+00	120	35	56	Site 2
3905, 3903, 3913 Bearwood Avenue (SFR)	1176+00	150	20	54	Site 3
3927, 3929 Bearwood Avenue (SFR)	1178+00	130	30	59	Site 3
3931, 4001, 4009 Bearwood Avenue (SFR)	1180+00	150	35	59	Site 3
4025, 4027, 4029 Bearwood Avenue (SFR)	1182+00	140	42	66 a	Site 3
4031, 4035, 4115 Bearwood Avenue (SFR)	1185+00	180	44	70 a	Site 3
4119, 4125 Bearwood Avenue (SFR)	1187+00	230	45	69 a	Site 3
4135, 4131, 4141 Bearwood Avenue (SFR)	1190+00	250	55	69 a	Site 3
4201 Howie Circle (SFR)	1194+00	200	55	61	Site 3
352, 358, 364 Leafmore Drive (SFR)	1195+00	65	55	69	Site 3
346, 372 Leafmore Drive (SFR)	1195+00	150	55	63	Site 3
4215 Howie Circle (SFR)	1195+00	125	55	64	Site 3
4235 Howie Circle (SFR)	1197+00	140	55	63	Site 3
4301 Howie Circle Vietnamese Baptist Church	1198+00	115	55	65	Site 3
4914, 4922, 4928 Clintwood Drive (SFR)	1199+00	180	55	61	Site 3
4934, 4942, 4948 Clintwood Drive (SFR)	1200+00	150	55	63	Site 3
4307, 4315, 4321 Howie Circle (SFR)	1201+00	200	55	61	Site 3
331 Barrymore Drive (SFR)	1201+00	120	55	64	Site 3
332 St. Anne Place (SFR)	1204+00	45	55	72	Site 3
4329, 4337 Howie Circle (SFR)	1205+00	280	55	59	Site 3
438 Eastway Drive (SFR)	1205+00	350	55	58	Site 3
341, 337, 333, 329, 325, 321 Prince Charles Street (SFR)	1207+00	100	55	66	Site 3
317 Prince Charles Street (SFR)	1208+00	120	55	64	Site 3
251 Eastway Drive Carolinas Medical Center - Northpark	1220+00	80	55	60	Site 3
5500 North Tryon Street/US-29 Crossroads Charter High School	2002+00	185	25	54	Site 3

Vibration Sensitive Receptor Location	Station Number	Distance to Near Track Centerline (feet)	Train Speed (mph)	Maximum Vibration Velocity in any 1/3-octave band from 4 to 80 Hz (VdB re: 1 μ-in/sec)	Projections Based on Vibration Test Site
5635 North Tryon Street/US-29 Pines Mobile Homes	2009+00	200	35	49	Site 4
5911 North Tryon Street/US-29 Star Motel	2028+00	70	35	56	Site 4
6001 North Tryon Street/US-29 Holiday Motel	2031+00	60	35	57	Site 4
6442 North Tryon Street/US-29 Fairyland Learning Center	2063+00	170	25	48	Site 4
6919 North Tryon Street/US-29 (SFR)	2088+00	350	45	49	Site 4
6811 Kemp Street (SFR)	2088+00	400	45	49	Site 4
110 W. Rocky River Rd Intown Suites Hotel	3004+00	220	40	50	Site 4
7706 North Tryon Street/US-29 Intown Suites Hotel	3020+00	140	40	54	Site 4
132 East McCullough Drive Microtel Inn	3038+00	120	29	51	Site 4
8419 North Tryon Street/US-29 Hampton Inn	3059+00	160	32	51	Site 4
8503 North Tryon Street/US-29 Marriott Residence Inn	3065+00	90	45	57	Site 4
8800 North Tryon Street/US-29 Carolinas Medical Center University	3075+00	240	45	50	Site 4
UNC Charlotte Epic Building	3090+00	1000	45	See Report	Site 5
UNC Charlotte Bioinformatics Building	3100+00	200	45	See Report	Site 5
UNC Charlotte| Grigg Hall	3100+00	500	45	See Report	Site 5
UNCC Charlotte Duke Centennial Hall	3100+00	500	45	See Report	Site 5
9303 Kitansett Drive Summit Green	3109+00	150	35	49	Site 5
North Tryon Street/US-29. CMF	3115+00	90	45	55	Site 5
UNC Charlotte Spruce Hall	3135+00	204	15	48	Site 5
UNC Charlotte Laurel Hall	3138+00	216	15	49	Site 5
UNC Charlotte Witherspoon Hall	3143+00	216	15	37	Site 5
a Vibration projections include contributions from special trackwork					

Appendix I Construction Vibration Projections for Potential Structural Damage

Receptor Location	Building Construction	Vibration Criterion for Potential Structural Damage in VdB_{RMS} (PPV in/s)	Construction Type	Construction Equipment	Distance from Equipment to Building (feet)	Vibration Level (VdB)	Potential Impact
301 East 7th Street[1]	Engineered Masonry	98 (0.3 in/s)	At-grade Track with Ballast Curb	Large Dozer/Backhoe	14[2]	94	No
				Small Dozer	14[2]	66	No
				Vibratory Roller	14[2]	102	Yes
301 East 8th Street[1]	Engineered Masonry	98 (0.3 in/s)	At-grade Track with Ballast Curb	Large Dozer/Backhoe	24[2]	87	No
				Small Dozer	24[2]	59	No
				Vibratory Roller	24[2]	95	No
301 East 9th Street	Engineered Masonry	98 (0.3 in/s)	At-grade Track, Retaining Wall and Station	Large Dozer/Backhoe (for retaining wall) (for station)	5[3] 16[5]	107 92	Yes No
				Small Dozer (for retaining wall) (for station)	5[3] 16[5]	79 64	No No
				Vibratory Roller (for retaining wall) (for station)	5[3] 16[5]	115 100	Yes Yes
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	5[3]	125 114 108	Yes Yes Yes
311 East 12th Street[1]	Engineered Masonry	98 (0.3 in/s)	Elevated Guideway with Retaining Walls	Large Dozer/Backhoe	80[3]	71	No
				Small Dozer	80[3]	43	No
				Vibratory Roller	80[3]	79	No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	80[3]	89 78 72	No No No
1019 Brevard Street	Engineered Masonry	98 (0.3 in/s)	Elevated Guideway with Retaining Walls	Large Dozer/Backhoe	65[3]	74	No
				Small Dozer	65[3]	46	No
				Vibratory Roller	65[3]	82	No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	65[3]	92 81 75	No No No
340 East 16th Street	Engineered Masonry	98 (0.3 in/s)	Elevated Guideway with Retaining Walls	Large Dozer/Backhoe	75[3]	72	No
				Small Dozer	75[3]	44	No
				Vibratory Roller	75[3]	80	No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	75[3]	90 79 73	No No No
451 Jordan Place[1]	Engineered Masonry	98 (0.3 in/s)	At-grade Track with Ballast Curb	Large Dozer/Backhoe	90[2]	69	No
				Small Dozer	90[2]	41	No
				Vibratory Roller	90[2]	77	No
430 East 36th Street[1]	Engineered Masonry	98 (0.3 in/s)	At-grade Track, Station and Retaining Wall for 36th Street Grade Separation	Large Dozer/Backhoe (for grade separation) (for track construction)	5[3] 35[5]	107 82	Yes No
				Small Dozer (for grade separation) (for track construction)	5[3] 35[5]	79 54	No No
				Vibratory Roller (for grade separation) (for track construction)	5[3] 35[5]	115 90	Yes No

Receptor Location	Building Construction	Vibration Criterion for Potential Structural Damage in VdB_{RMS} (PPV in/s)	Construction Type	Construction Equipment	Distance from Equipment to Building (feet)	Vibration Level (VdB)	Potential Impact
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	5[3]	125 114 108	Yes Yes Yes
300 East 36th Street	Engineered Masonry	98 (0.3 in/s)	At-grade Track, Retaining Wall on NCRR ROW and Retaining Wall for 36th Street Grade Separation	<u>Large Dozer/Backhoe</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation) (for track construction)	16[3] 35[3] 35[5]	92 82 82	No No No
				<u>Small Dozer</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation) (for track construction)	16[3] 35[3] 35[5]	64 54 54	No No No
				<u>Vibratory Roller</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation) (for track construction)	16[3] 35[3] 35[5]	100 90 90	Yes No No
				<u>Sheet Pile Driver (Impact)</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation)	16[3] 35[3]	110 100	Yes Yes
				<u>Sheet Pile Driver (Sonic)</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation)	16[3] 35[3]	99 89	Yes No
				<u>Auger Drilling</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation)	16[3] 35[3]	93 83	No No
315 East 36th Street[1]	Engineered Masonry, Metal Shed, Metal Parking Garage and Metal Support for Pressure Vessels	<u>Masonry</u> 98 (0.3 in/s) <u>Metal</u> 102(0.5 in/s)	At-grade Track, Retaining Wall on NCRR ROW and Retaining Wall for 36th Street Grade Separation	<u>Large Dozer/Backhoe</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation) (for track construction)	10[3] 15[3] 25[5]	98 93 86	No[6] No[7] No[6]
				<u>Small Dozer</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation) (for track construction)	10[3] 15[3] 25[5]	70 65 58	No[6] No[7] No[6]
				<u>Vibratory Roller</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation) (for track construction)	10[3] 15[3] 25[5]	106 101 94	Yes[6] Yes[7] No[6]
				<u>Sheet Pile Driver (Impact)</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation)	10[3] 15[3]	116 111	Yes[6] Yes[7]
				<u>Sheet Pile Driver (Sonic)</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation)	10[3] 15[3]	105 100	Yes[6] Yes[7]
				<u>Auger Drilling</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation)	10[3] 15[3]	99 94	No[6] No[7]
407 East 36th Street[1]	Engineered Masonry and Timber	<u>Masonry</u> 98 (0.3 in/s) <u>Timber</u> 102(0.5 in/s)	At-grade Track, Retaining Wall on NCRR ROW and Retaining Wall for 36th Street Grade Separation	<u>Large Dozer/Backhoe</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation) (for track construction)	10[3] 30[3] 20[5]	98 84 89	No[8] No[7] No[8]
				<u>Small Dozer</u> (for retaining wall – NCRR ROW) (for 36th Street grade separation) (for track construction)	10[3] 30[3] 20[5]	70 56 61	No[8] No[7] No[8]
				<u>Vibratory Roller</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation) (for track construction)	10[3] 30[3] 20[5]	106 92 97	Yes[8] No[7] No[8]
				<u>Sheet Pile Driver (Impact)</u> (for retaining wall - NCRR ROW) (for 36th Street grade separation)	10[3] 30[3]	116 102	Yes[8] Yes[7]

Receptor Location	Building Construction	Vibration Criterion for Potential Structural Damage in VdB_{RMS} (PPV in/s)	Construction Type	Construction Equipment	Distance from Equipment to Building (feet)	Vibration Level (VdB)	Potential Impact
				Sheet Pile Driver (Sonic) (for retaining wall - NCRR ROW) (for 36th Street grade separation)	10[3] 30[3]	105 91	Yes[8] No[7]
				Auger Drilling (for retaining wall - NCRR ROW) (for 36th Street grade separation)	10[3] 30[3]	99 85	No[8] No[7]
3327 North Davidson Street	Engineered Masonry	98 (0.3 in/s)	At-grade Track and Retaining Wall	Large Dozer/Backhoe (for retaining wall) (for track construction)	25[3] 35[5]	86 82	No No
				Small Dozer (for retaining wall) (for track construction)	25[3] 35[5]	58 54	No No
				Vibratory Roller (for retaining wall) (for track construction)	25[3] 35[5]	94 90	No No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	25[3]	104 93 87	Yes No No
600 East Sugar Creek Road[1]	Engineered Masonry	98 (0.3 in/s)	At-grade Track and Station	Large Dozer/Backhoe	58[5]	75	No
				Small Dozer	58[5]	47	No
				Vibratory Roller	58[5]	83	No
601 East Sugar Creek Road[1]	Engineered Masonry	98 (0.3 in/s)	At-grade Track and Retaining Wall	Large Dozer/Backhoe (for retaining wall) (for track construction)	12[3] 20[5]	96 89	No No
				Small Dozer (for retaining wall) (for track construction)	12[3] 20[5]	68 61	No No
				Vibratory Roller (for retaining wall) (for track construction)	12[3] 20[5]	104 97	Yes No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	12[3]	114 103 97	Yes Yes No
4242 Raleigh Street	Engineered Masonry	98 (0.3 in/s)	At-grade Track	Large Dozer/Backhoe	60[5]	75	No
				Small Dozer	60[5]	47	No
				Vibratory Roller	60[5]	83	No
4300 Raleigh Street	Metal	102(0.5 in/s)	At-grade Track and Retaining Wall	Large Dozer/Backhoe (for retaining wall) (for track construction)	30[3] 38[5]	84 81	No No
				Small Dozer (for retaining wall) (for track construction)	30[3] 38[5]	56 53	No No
				Vibratory Roller (for retaining wall) (for track construction)	30[3] 38[5]	92 89	No No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	30[3]	102 91 85	Yes No No
332 St. Anne Place	Timber	102(0.5 in/s)	At-grade Track and Retaining Wall	Large Dozer/Backhoe (for retaining wall) (for track construction)	18[3] 40[5]	90 80	No No
				Small Dozer (for retaining wall) (for track construction)	18[3] 40[5]	62 52	No No
				Vibratory Roller (for retaining wall) (for track construction)	18[3] 40[5]	98 88	No No

Receptor Location	**Building Construction**	**Vibration Criterion for Potential Structural Damage in VdB_{RMS} (PPV in/s)**	**Construction Type**	**Construction Equipment**	**Distance from Equipment to Building (feet)**	**Vibration Level (VdB)**	**Potential Impact**
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	18[3]	108 97 91	Yes No No
325, 329, 333, 337, 341 Prince Charles Street	Timber	102(0.5 in/s)	At-grade Track and Retaining Wall	<u>Large Dozer/Backhoe</u> (for retaining wall) (for track construction)	60[3] 82[5]	75 71	No No
				<u>Small Dozer</u> (for retaining wall) (for track construction)	60[3] 82[5]	47 43	No No
				<u>Vibratory Roller</u> (for retaining wall) (for track construction)	60[3] 82[5]	83 79	No No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	60[3]	93 82 76	No No No
5500 North Tryon Street/US-29[1]	Engineered Masonry	98 (0.3 in/s)	Elevated Guideway with Retaining Wall	Large Dozer/Backhoe	160[3]	62	No
				Small Dozer	160[3]	34	No
				Vibratory Roller	160[3]	70	No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	160[3]	80 69 63	No No No
5608 Old Concord Road	Metal	102(0.5 in/s)	Elevated Guideway with Retaining Wall and Bridge	Large Dozer/Backhoe	45[3]	78	No
				Small Dozer	45[3]	50	No
				Vibratory Roller	45[3]	86	No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic)	45[3]	96 85	No No
				Pier Pile Driver (Impact) Pier Pile Driver (Sonic) Auger Drilling	60[9]	93 82 76	No No No
5612 Old Concord Road	Metal	102(0.5 in/s)	Elevated Guideway with Retaining Wall and Bridge	Large Dozer/Backhoe	70[3]	73	No
				Small Dozer	70[3]	45	No
				Vibratory Roller	70[3]	81	No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	70[3]	91 80 74	No No No
				Pier Pile Driver (Impact) Pier Pile Driver (Sonic) Auger Drilling	70[9]	91 80 74	No No No
5625 North Tryon Street/US-29	Timber	102(0.5 in/s)	Elevated Guideway Bridge	Large Dozer/Backhoe	90[9]	69	No
				Small Dozer	90[9]	41	No
				Vibratory Roller	90[9]	77	No
				Pier Pile Driver (Impact) Pier Pile Driver (Sonic) Auger Drilling	90[9]	87 76 70	No No No
5636 North Tryon Street/US-29	Metal	102(0.5 in/s)	Elevated Guideway Bridge	Large Dozer/Backhoe	70[9]	73	No
				Small Dozer	70[9]	45	No
				Vibratory Roller	70[9]	81	No
				Pier Pile Driver (Impact) Pier Pile Driver (Sonic) Auger Drilling	70[9]	91 80 74	No No No

Receptor Location	Building Construction	Vibration Criterion for Potential Structural Damage in VdB_{RMS} (PPV in/s)	Construction Type	Construction Equipment	Distance from Equipment to Building (feet)	Vibration Level (VdB)	Potential Impact
5655 and 5703 North Tryon Street/US-29	Masonry	98 (0.3 in/s)	Elevated Guideway with Retaining Wall and Road	Large Dozer/Backhoe and Hoe Ram	70[10]	74	No
				Small Dozer	85[3]	42	No
				Vibratory Roller	85[3]	78	No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	85[3]	88 77 71	No No No
5716, 5732, 5740 North Tryon Street/US-29	Masonry	98 (0.3 in/s)	Elevated Guideway with Retaining Wall and Road	Large Dozer/Backhoe and Hoe Ram	40[10]	81	No
				Small Dozer	60[3]	47	No
				Vibratory Roller	60[3]	83	No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	60[3]	93 82 76	No No No
5911 North Tryon Street/US-29	Masonry	98 (0.3 in/s)	Road	Large Dozer/Backhoe and Hoe Ram	20[10]	85	No
6001 North Tryon Street/US-29	Masonry	98 (0.3 in/s)	Road	Large Dozer/Backhoe and Hoe Ram	20[10]	85	No
6709 North Tryon Street/US-29	Masonry	98 (0.3 in/s)	At-grade Track and Road	Large Dozer/Backhoe and Hoe Ram	60[10]	76	No
				Small Dozer	100[2]	40	No
				Vibratory Roller	100[2]	76	No
7850 North Tryon Street/US-29	Masonry	98 (0.3 in/s)	At-grade Track and Road	Large Dozer/Backhoe and Hoe Ram	30[10]	85	No
				Small Dozer	100[2]	40	No
				Vibratory Roller	100[2]	76	No
8001 North Tryon Street/US-29	Masonry	98 (0.3 in/s)	At-grade Track and Road	Large Dozer/Backhoe and Hoe Ram	20[10]	85	No
				Small Dozer	75[2]	44	No
				Vibratory Roller	75[2]	80	No
8503 North Tryon Street/US-29	Masonry	98 (0.3 in/s)	Road	Large Dozer/Backhoe and Hoe Ram	40[10]	81	No
8926 North Tryon Street/US-29	Masonry	98 (0.3 in/s)	Road	Large Dozer/Backhoe and Hoe Ram	20[10]	85	No

1 Building is a registered historic property
2 Distance is from building to ballast curb
3 Distance is from building to retaining wall
4 Distance is from building to station platform
5 Distance is from building to near rail of near track
6 Potential impact assessed for metal structure
7 Potential impact assessed for masonry structure
8 Potential impact assessed for timber structure
9 Distance is from building to bridge pier support
10 Distance is from building to edge of road

Appendix J Construction Vibration Projections for Potential Impact to Vibration-sensitive Equipment

Receptor Location	Building Construction	Vibration Criterion for Potential Short-term Impact to Sensitive Equipment VdB_{RMS}	Construction Type	Construction Equipment	Distance from Equipment to Building (feet)	Vibration Level (VdB)	Potential Impact
CRI - Bioinformatics	Masonry	60 (VC-B)	At-grade Track with Retaining Wall and Underpass	Large Dozer/Backhoe	200[1]	49	No
				Small Dozer	200[1]	21	No
				Vibratory Roller	200[1]	57	No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	200[1]	67 56 50	Yes No No
CRI – Duke Centennial Hall	Masonry	42 (VC-E)	At-grade Track with Retaining Wall and Underpass	Large Dozer/Backhoe	500[1]	37	No
				Small Dozer	500[1]	9	No
				Vibratory Roller	500[1]	45	Yes
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	500[1]	55 44 38	Yes Yes No
CRI – Grigg Hall	Masonry	42 (VC-E)	At-grade Track with Retaining Wall and Underpass	Large Dozer/Backhoe	550[1]	36	No
				Small Dozer	550[1]	8	No
				Vibratory Roller	550[1]	44	Yes
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	550[1]	54 43 37	Yes Yes No
CRI – EPIC Building	Masonry	42 (VC-E)	At-grade Track with Retaining Wall and Underpass	Large Dozer/Backhoe	1250[1]	25	No
				Small Dozer	1250[1]	-3	No
				Vibratory Roller	1250[1]	33	No
				Sheet Pile Driver (Impact) Sheet Pile Driver (Sonic) Auger Drilling	1250[1]	43 32 26	Yes No No
1 Distance is from building to retaining wall							

Appendix K Maximum Allowable Construction Equipment Noise Emissions

Construction Equipment	Maximum Sound Level at 50 ft (dBA, slow)
Auger Drill Rig	85
Backhoe	80
Bar Bender	80
Blasting	94
Boring Jack Power Unit	80
Chain Saw	85
Clam Shovel	93
Compactor (ground)	80
Air Compressor	80
Concrete Batch Plant	83
Concrete Mixer Truck	85
Concrete Pump	82
Concrete Saw	90
Crane	85
Dozer	85
Dump Truck	84
Excavator	85
Flat Bad Truck	84
Front End Loader	80
Generator (25 KVA or less)	70
Generator (over 25 KVA)	82
Gradall	85
Grader	85
Horizontal Boring Jack	80
Hydraulic Break Ram	90
Impact Pile Driver	95
Insitu Soil Sampling Rig	84
Jackhammer	85
Mounted Hammer (ram)	90
Paver	85
Pickup Truck	55
Pneumatic Tools	85

Construction Equipment	Maximum Sound Level at 50 ft (dBA, slow)
Pumps	77
Rock Drill	85
Scraper	85
Slurry Plant	78
Slurry Trenching Machine	82
Soil Mix Drill Rig (Jet Grouting)	80
Tractor	84
Vacuum Excavator	85
Vacuum Street Sweeper	80
Vibratory Concrete Mixer	80
Vibratory Pile Driver	95
Welder	73
All Other Equipment > 5 HP	85