

NOISE AND VIBRATION TECHNICAL STUDY

Seismic Retrofit of BART Aerial Structures and Stations along the Concord, Richmond, Daly City and Fremont Lines

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Noise and Vibration Technical Study

Seismic Retrofit of BART Aerial Structures and Stations along the Concord, Richmond, Daly City and Fremont Lines



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1. Summary

This Noise and Vibration Technical Study presents the results of a construction noise and vibration impact assessment performed for the Seismic Retrofit of BART Aerial Structures and Stations along the Concord, Richmond, Daly City and Fremont Lines Project (Proposed Project). The noise analysis was based on a construction scenario for both the safety retrofit and the operability retrofit for the BART system. The land use survey was conducted during the week of March 27, 2006 and noise measurements were conducted on June 1-2, 2006.

The construction noise and vibration impact criteria utilized in this report are taken from the BART Design Criteria for noise and the Federal Transit Administration Transit Noise and Vibration Impact Assessment Guidance Manual, which contain noise criteria for both continuous and intermittent noise and vibration criteria for a variety of land uses.

Projecting continuous construction noise levels requires a construction scenario of the equipment likely to be used and the average utilization factors or duty cycles. Using typical sound emission characteristics, it is then possible to estimate the continuous noise level at various distances from the construction site. The continuous noise impact assessment for a construction site is based on: an estimate of the type of equipment that will be used during the construction and the average daily duty cycle for each category of equipment,

typical noise emission levels for each category of equipment, and estimates of noise attenuation as a function of distance from the construction site.

Projecting intermittent construction noise levels requires only a construction scenario of the equipment likely to be used. Intermittent noise levels are a function of the maximum noise levels, and of the noise attenuation as a function of distance from the construction site.

The assessment of construction vibration is based on the maximum vibration levels generated by a specific piece of equipment. Typically, only activities such as pile driving, hoe ramming, or vibratory compacting have the potential to generate vibration levels that would exceed the Federal Transit Administration (FTA) vibration criteria. For this assessment, the only types of construction equipment with the potential to generate sufficient vibration levels to exceed the criteria are vibratory rollers and possibly sheet piling at Alameda Creek and Daly City.

The results of the analysis indicate that with noise mitigation including contract specifications to limit noise levels, no noise impact is projected. There is no vibration impact projected from this project because there are no sensitive receptors located within the area of potential impact of construction activities such as pile driving which have potential to cause vibration impacts.

2. Introduction

2.1. Introduction

The Seismic Retrofit of the Bay Area Rapid Transit District (BART) Aerial Structures and Stations along the Concord, Richmond, Daly City, and Fremont lines (Proposed Project) will be implemented as part of the overall BART Earthquake Safety Program. (All references to “stations” in this report refer to BART stations.) The objective of the program and the Proposed Project is to retrofit the original BART system operating facilities to protect passengers and preserve the BART system during a major earthquake.

Construction of the original BART system concluded in 1972 and consisted of the Concord, Daly City, Fremont and Richmond lines. System extensions, built since the 1989 Loma Prieta earthquake, employed more stringent and up-to-date seismic criteria and do not require upgrades. Figure 1 shows the existing BART system. The aerial structures and elevated stations that would be retrofitted as part of the Proposed Project are identified in Figure 2.

The BART Earthquake Safety Program derives its funding from a combination of sources, including the voter-approved Measure AA, passed in November 2004, and Regional Measure 2. Some components of the overall Earthquake Safety Program are state and locally funded, while others are funded by federal or federalized state funding sources, specifically the California Department of Transportation (Caltrans) Local Seismic Safety Retrofit Program (LSSRP), the



Figure 1: Project Vicinity Map

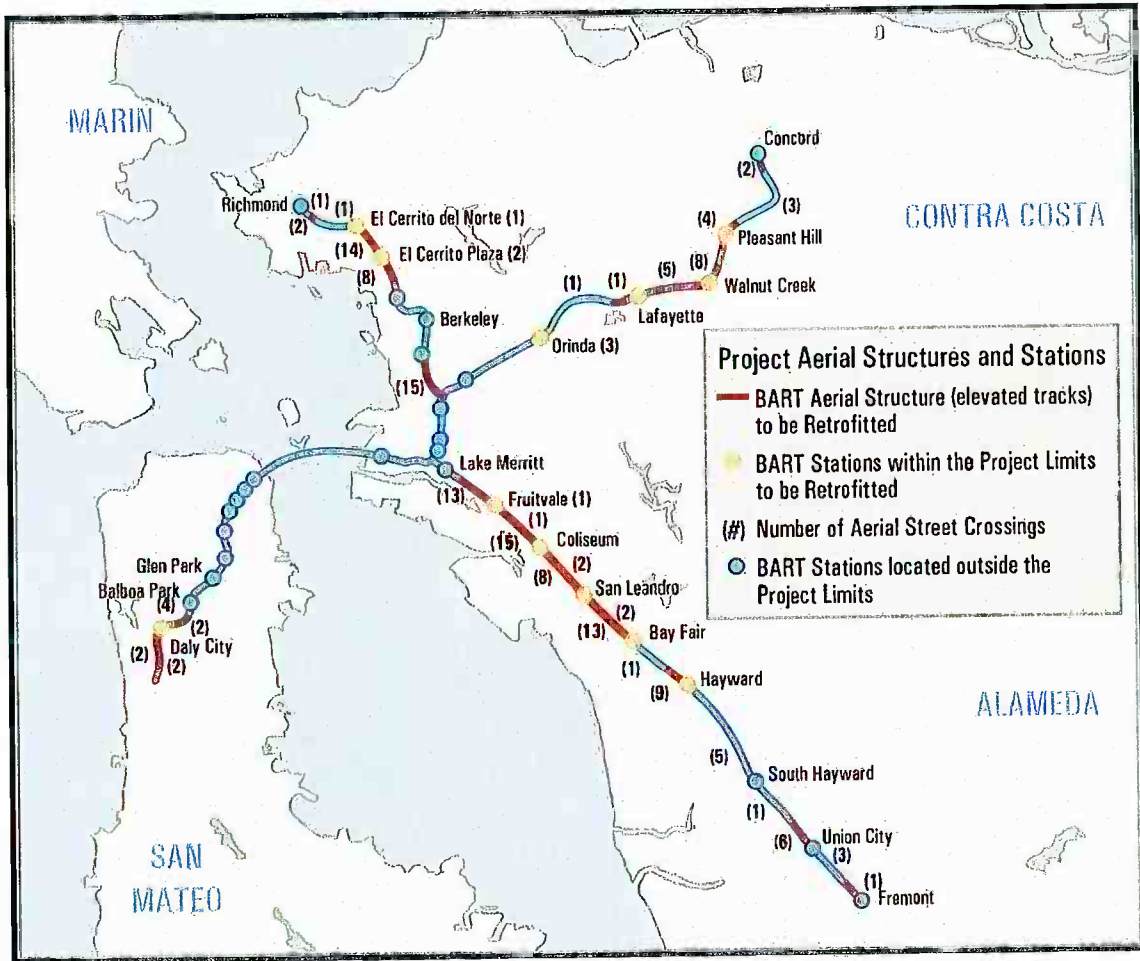


Figure 2: Project Limits

State Transportation Improvement Program (STIP) and the federal Surface Transportation Program (STP). Pursuant to a May 2001 Memorandum of Understanding between BART and Caltrans, the LSSRP funds are to be used solely for the seismic retrofit of 1,578 aerial BART structures, which cross public streets. Figure 2 identifies the number of street overcrossings in the Proposed Project area.

Additional information about the Earthquake Safety program can be found on the BART Earthquake Safety Program website (www.bart.gov/about/projects/earthquakesafety.asp), including the text of the Seismic Vulnerability Study, program funding sources, seismic event information and a list of the project technology advisors responsible for reviewing the seismic retrofit strategies and concepts.

2.2. Purpose and Need

The Proposed Project's seismic upgrade is needed to address life safety issues and prevent BART facilities from prolonged interruption due to an earthquake event in the San Francisco Bay Area. The project is being proposed to protect the public and the massive capital investment represented by the BART system.

2.2.1. Background

The BART system is one of the San Francisco Bay Area's most vital transportation links, averaging about 300,000 riders every day. The BART system represents a public investment currently valued at nearly \$15 billion, with immeasurable importance to the local and regional economy. BART's success in maintaining continuous service directly after the Loma Prieta earthquake of 1989 reconfirmed the system's importance as a transportation "lifeline." However, the Loma Prieta earthquake may not be the biggest test of BART's ability to withstand seismic impact. A U.S. Geological Survey statistical analysis predicts a high probability of one or more major earthquakes hitting the Bay Area within the next 30 years.

The Proposed Project covers the original BART system from Oakland to Concord, Richmond, Fremont and Daly City with the exclusion of west from the Berkeley Hills tunnel to the Montgomery Street Station in San Francisco. This portion of the BART system often referred to as the "Core System" was implemented in an earlier project.

The Proposed Project includes the seismic retrofit of the aerial structures and stations. The aerial structures and stations proposed to be retrofitted are shown in Figure 2. A description of the Proposed Project and the proposed construction scenario are provided below. Project elements are presented according to the specific BART line in which they occur (i.e., the Concord, Richmond, Daly City, and Fremont lines).

Additional components of the Earthquake Safety Program, which are not included in the Proposed Project, include the BART offices, shops, training facilities, and systems such as train control and communications. Seismic safety projects that address these additional components do not require federal environmental review.

2.2.2. Project Elements

The Proposed Project includes approximately 21 linear miles of the BART system, including aerial structures and stations within the original BART system, which was completed in 1972. Seismic studies have determined that aerial structures may suffer damage from an earthquake. A description of the retrofit strategies and concepts that are expected to be used along the aerial structures and

stations are provided below, followed by a brief description of each of the aerial structures, street overcrossings, and stations that would be seismically retrofitted as part of the Proposed Project.

2.2.3. Aerial Structures

Within the Proposed Project area, the most common aerial structure in the BART system consists of a single-column reinforced concrete pier on either pile-supported or spread concrete footings. Existing columns have one of three different cross-sectional shapes: rectangular, hexagonal, or circular. On top of the column are pier caps and shear keys, which support the pre-cast concrete girders.¹ Aerial structure components are shown in Figure 3.

The Proposed Project includes two design strategies for the seismic retrofits – Operability and Safety. Aerial structures between the Daly City Yard and the west portal of the Berkeley Hills Tunnel are on what BART refers to as the “Core System”. This study includes the elevated sections of the Core System between Balboa Park Station and the Daly City Yard. Facilities along this segment will be retrofitted to a degree so they will be able to resume operations shortly after a major earthquake. This level of retrofit is known as the Operability retrofit strategy. Other facilities will be retrofitted to a degree to which passengers will be protected but operations may be disrupted. This level of retrofit is known as the Safety retrofit strategy. Examples of these two typical retrofits for aerial structures are shown in Figure 3.

The Operability retrofit strategy (see Figure 3) would include widening the foundation and installing additional piles. It would also include new column jackets and shear key support where needed.

¹ Girders are the beam-like members between columns on which the trains run. Pier caps are the arm-like members on the columns. Shear keys are the connectors that keep the girders on the pier caps. An abutment is a foundation that allows the horizontal member of a bridge to transit to the ground.

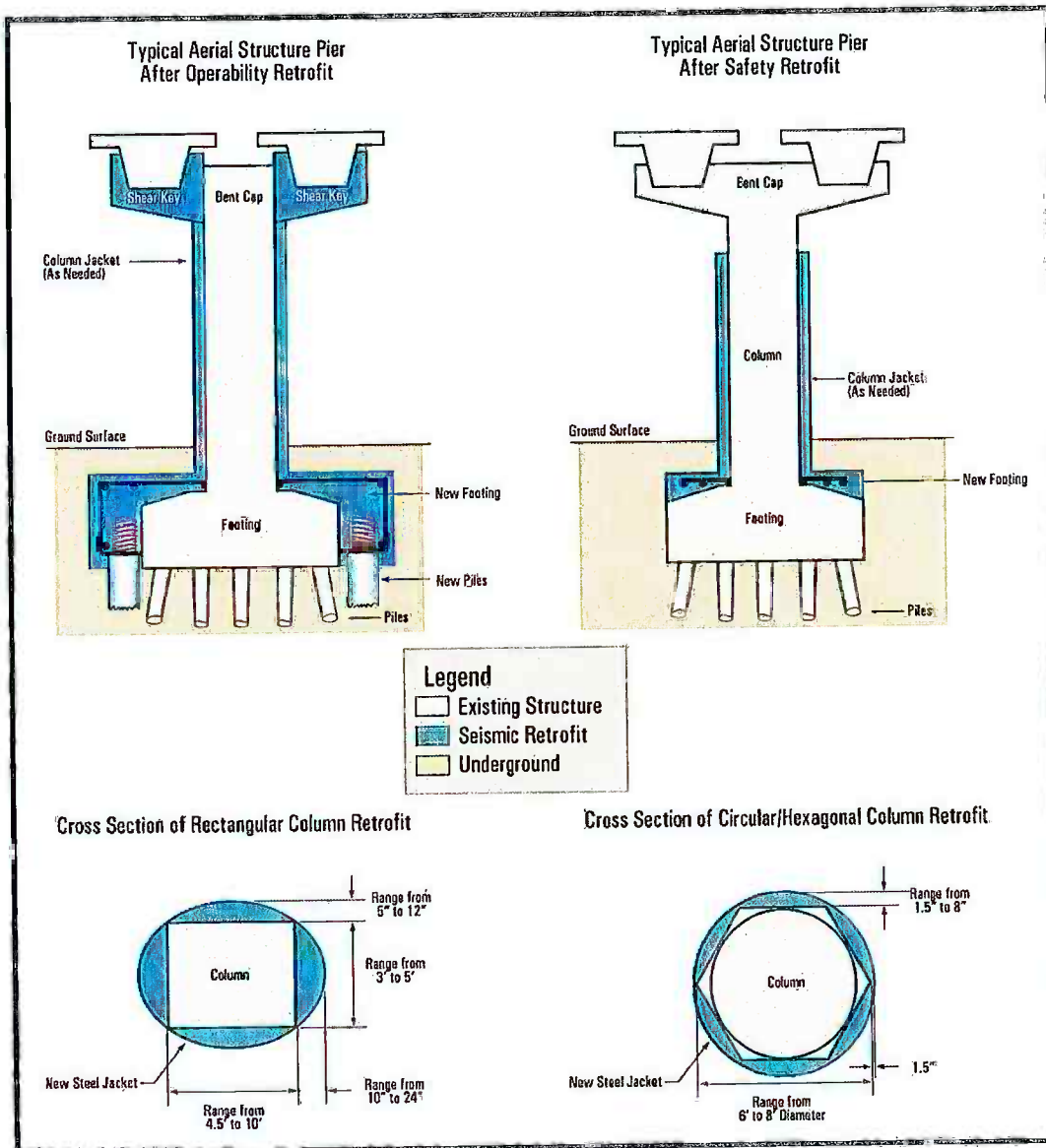


Figure 3: Safety and Operability Retrofit

Proposed seismic retrofit strategies and concepts for the Core System generally include:

- a. Additional Cast in Drilled Hole (CIDH) piles or other non-driven piles would be installed in the areas around the perimeter of the existing foundations.
- b. Enlargement of the existing foundation to be approximately five to eight feet wider on each side and approximately two feet thicker by adding a concrete topping including placement of a top mat of rebar and new vertical and horizontal dowels into the existing foundation.
- c. Jacketing (encasing) of the concrete columns with Fiberwrap or 3/8- to 1-inch thick steel casings or collars. Steel jacketing encircling a column would be round or elliptical in shape, depending on the original shape of the column, and filled with concrete or grout. Fiberwrap is a material made of a combination of specialized fabrics and resins to form a strong two-dimensional material that can be bonded (wrapped) onto concrete to enhance the structural performance of the column.
- d. Placement of additional shear keys at the bent caps where needed. A shear key is a structural element installed to prevent the relative movement between two adjoining structures. A shear key retrofit consists of a concrete or steel structure connecting the girder to the bent cap; see Figure 4.
- e. At some abutment or bent cap locations, concrete seat extenders may be added to increase the available seating area for the girders. These extenders, typically consisting of a concrete block, are added to a structure to increase the support for an aerial girder. Extenders are installed to reduce the possibility of the girder being shaken off of its support during excessive earthquake movement (see Figure 4).

The Operability retrofit strategies are illustrated in Figure 3 and Figure 4. Similar types of retrofits may be done at street overcrossings. Retrofits similar to the aerial structure columns would occur at the overcrossing columns and abutments.

Substations which provide electrical power to the BART trains and gap breakers which divide the power system so that power can be provided to segments on the BART system are spread throughout the BART system. At some locations within the Proposed Project area, substation and gap breakers may have been constructed on top of existing aerial column footings. Where this occurs, the Proposed Project includes either temporary or permanent relocation of these facilities. In all instances, the facilities would be relocated within the Proposed Project limits.

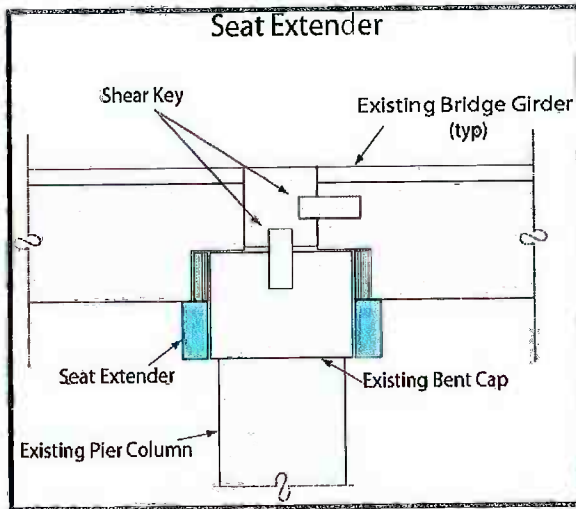


Figure 4: Typical Seat Extender Retrofit

Certain substations and gap breakers near columns may be damaged during an earthquake. These facilities may be moved or the column retrofit may be modified.

The Safety retrofit strategy (see Figure 3) for the aerial structures along the Concord, Richmond, and Fremont lines generally includes:

- a. Thicken the existing foundation by approximately two feet by adding a concrete topping. This includes a top mat of rebar with new vertical dowels into the existing foundation.
- b. Jacketing (encasing) of the concrete columns with Fiberwrap or 3/8- to 1-inch thick steel casings or collars. Steel jacketing encircling a column would be round or elliptical in shape, depending on the original shape of the column, and filled with concrete or grout.
- c. Placement of additional shear keys at the bent caps where needed.
- d. At some abutment or bent cap locations, concrete seat extenders may be added to increase the available seating area for the girders. These extenders, typically consisting of a concrete block, are added to a structure to increase the support for an aerial girder. Extenders are installed to reduce the possibility of the girder being shaken off of its support during excessive earthquake movement (see Figure 4).

2.2.4. Stations

The construction methods described for aerial structures would also apply to the columns supporting aerial BART stations. The Proposed Project includes retrofitting ten stations. Foundation retrofits for stations are similar to aerial structures, as shown in Figure 3. At stations and areas where there

are multi-column footings or foundations (bents that have between two to six columns instead of just one), concrete shear walls would be installed between the columns, as shown in Figure 5. At locations where there are physical conflicts or visibility and security concerns, moment frame improvements may be made. This involves strengthening the connections between the horizontal and vertical members of the structure. Another method would be to create openings in the new shear walls to increase visibility. In areas where multiple columns are located within a sensitive view area, the column jackets would be installed to the same height on each pier for a consistent look.

2.2.5. Retrofit Locations

Retrofit locations are grouped by line as described below.

2.2.5.1. Concord Line

There are six stretches of aerial structure (traversing a total of two stations), that include a total of 219 columns, nine street overcrossings (one of which is adjacent to a station), and one station above a street. Figure 6 shows the area of work along the Concord line.

The Orinda Station is built above Camino Pablo. In addition to the platform overcrossing, the station includes a pedestrian overcrossing and a vehicle overcrossing between BART parking lots east and west of Camino Pablo.

Lafayette West – This section of aerial structure lies in the median of State Route 24 (SR 24) in Lafayette. The western limit of this section of aerial structure is the abutment approximately 400 feet west of Pine Lane. The eastern limit of this section is the abutment about 100 feet east of Pine Lane.

Lafayette East – This section lies in the median of SR 24 in Lafayette. The western limit of this section of aerial structure is the abutment approximately 500 feet west of Brown Avenue. The eastern limit of this section is the abutment about 100 feet east of Brown Avenue.

Walnut Creek West – This section parallels SR 24 in Walnut Creek. The western limit of this section is the abutment approximately 500 feet west of Springbrook Road. The eastern limit is the abutment approximately 100 feet east of Springbrook Road.

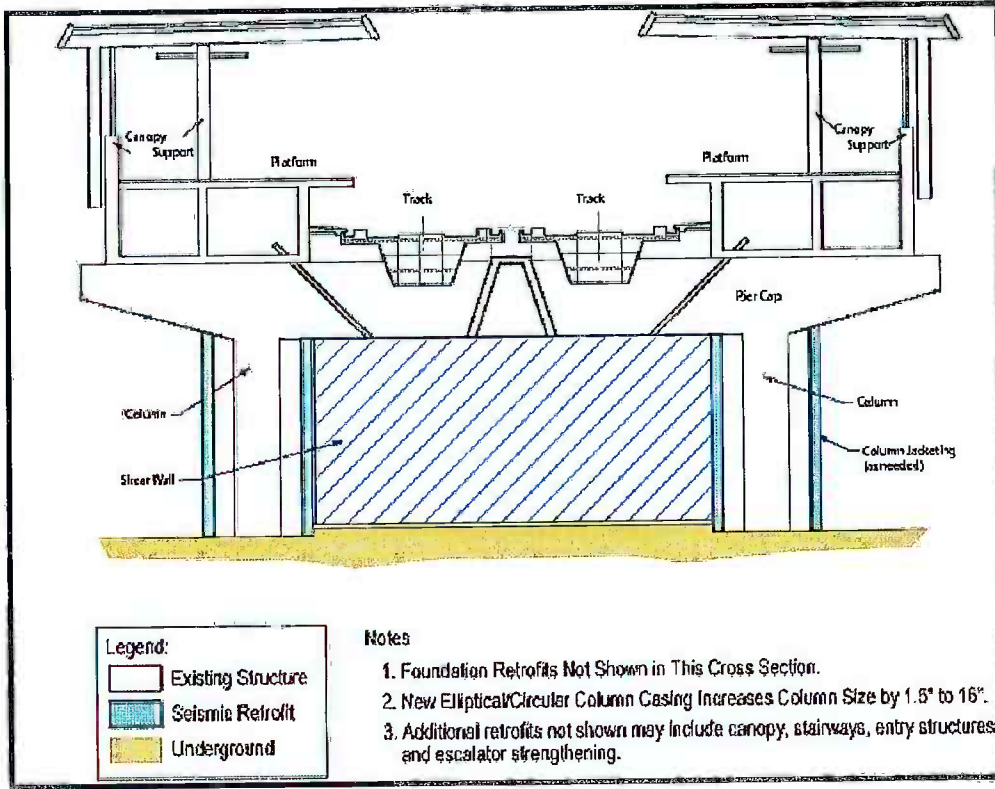


Figure 5: Typical Aerial Station Retrofit Strategy

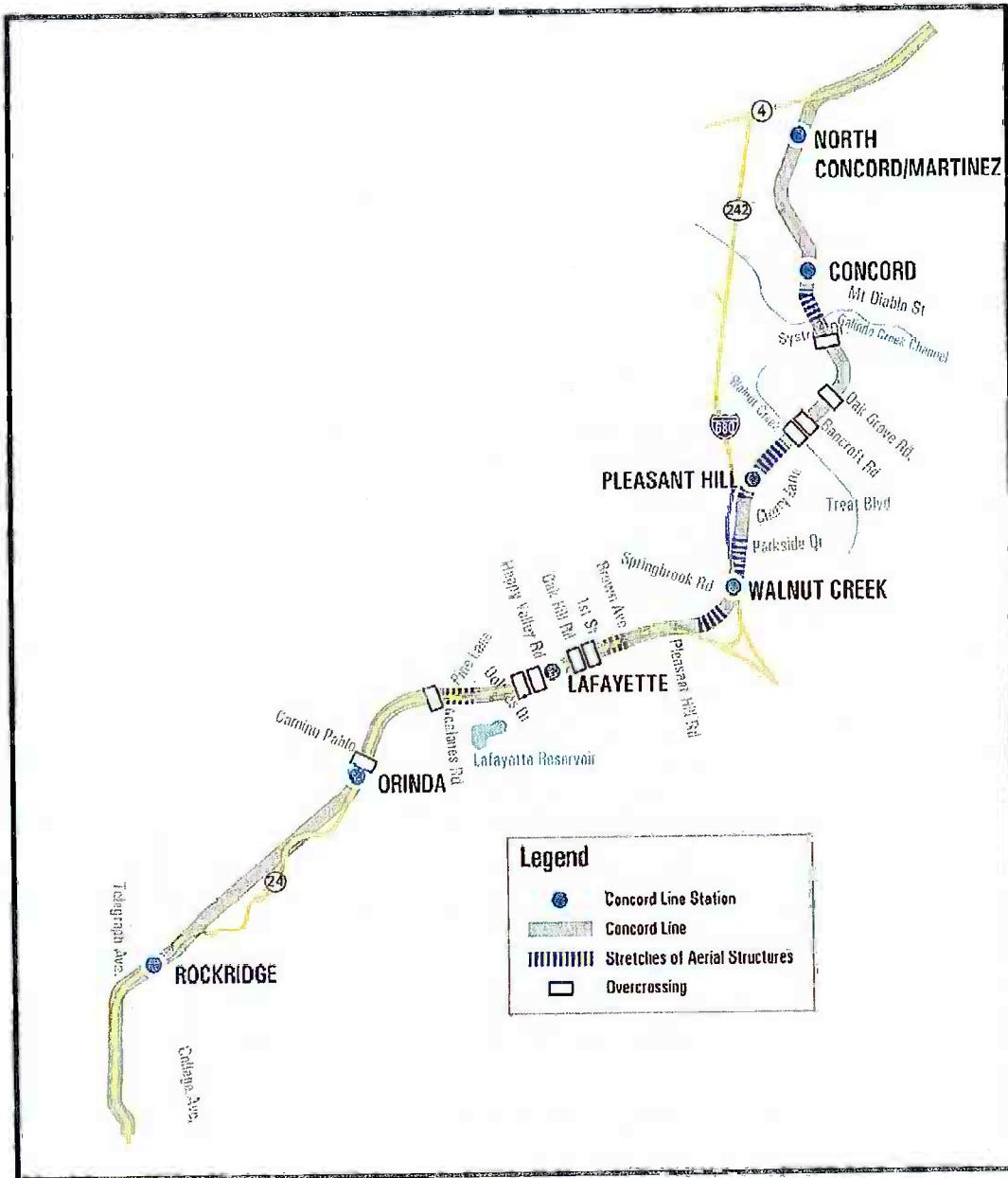


Figure 6: Concord Line Station

Walnut Creek East – The western limit of this section is the abutment on the west side of I-680. This section traverses the Walnut Creek Station, an aerial station. The northern limit of this section is the abutment near Parkside Drive.

Pleasant Hill – The southern limit of this section is the abutment south of Treat Boulevard in Walnut Creek. This section traverses the Pleasant Hill Station, an aerial station. The northern limit of this section is the abutment near Cherry Lane.

Concord – The western limit of this section is the abutment near the Galindo Creek Channel in Concord. The northern limit of this section is the abutment at Mt. Diablo Street.

The Concord Line stations that are located along aerial line or are above or adjacent to road crossings include:

- Orinda
- Lafayette
- Walnut Creek
- Pleasant Hill

Retrofits of overcrossings at the following streets are also needed on the Concord Line.

- Retrofits may be needed between the Orinda and Lafayette Stations at Acalanes Road, Dolores Road, and Happy Valley Road.
- Between the Lafayette and Walnut Creek Stations, retrofits may be needed at Oak Hill Road, Lafayette, First Street, and Pleasant Hill Road.
- Retrofits may be needed between the Pleasant Hill Stations at Bancroft Road, Oak Grove Road, and Systron Drive.

Retrofits of stream crossings in Concord include bridges over Walnut Creek, Pine Creek and Galindo Creek. Since it is not contiguous to any aerial structures or road crossings, the Concord Station is not included.

2.2.5.2. Richmond Line

There are three stretches of aerial structure along the Richmond line, which include a total of 390 columns and traverse a total of two stations. Figure 7 shows the areas of work along the Richmond line.



Figure 7: Richmond Line

Richmond – The northern limit of this section is the abutment near 21st Street. The southern limit of the section is the abutment near Broadway.

El Cerrito/Albany/Berkeley – This section largely traverses the Ohlone Greenway in El Cerrito and Albany. The northern limit of this section is the abutment east of I-80 in El Cerrito. This section traverses the El Cerrito del Norte and El Cerrito Plaza Stations, both of which are aerial stations. The southern limit of this section is the abutment near Neilson Street in Berkeley.

Oakland/Berkeley – This section parallels Martin Luther King, Jr. Way in Oakland. The northern limit of this stretch of aerial structure is the abutment near 62nd Street. The southern limit of this section is the abutment near 47th Street.

Retrofits of overcrossings are also needed on the Richmond Line. This includes the overcrossing at Barrett Avenue which is north of the Richmond Station; the aerial alignment between the Richmond and El Cerrito del Norte Stations; and the overcrossings at MacDonald Avenue and 37th Street.

The El Cerrito del Norte and El Cerrito Plaza Stations are located along the aerial structures and are therefore included in the analysis.

No substations or gap breakers would be affected by the Proposed Project along Richmond line.

2.2.5.3. Daly City Line

There are two stretches of aerial structure on this line, one of which abuts a station, the Daly City Station. Figure 8 shows the areas of work along the Daly City line. No substations or gap breakers would be relocated along the Concord line.

San Francisco – This section lies between I-280 and Alemany Boulevard in San Francisco. The northern limit of this section is the abutment near Cayuga Park. The southern limit of this section is the abutment near Crystal Street.

Daly City – This section parallels I-280 in Daly City. The northern limit of this section is the Daly City station. The south side of which is aerial and north side is at grade. The southern limit of the section is the abutment near Citrus Avenue.

Retrofits of up to four gap breakers or sub stations along the Daly City line will also be done. The Daly City Station is contiguous with the aerial structure through Daly City and is therefore included in the analysis.

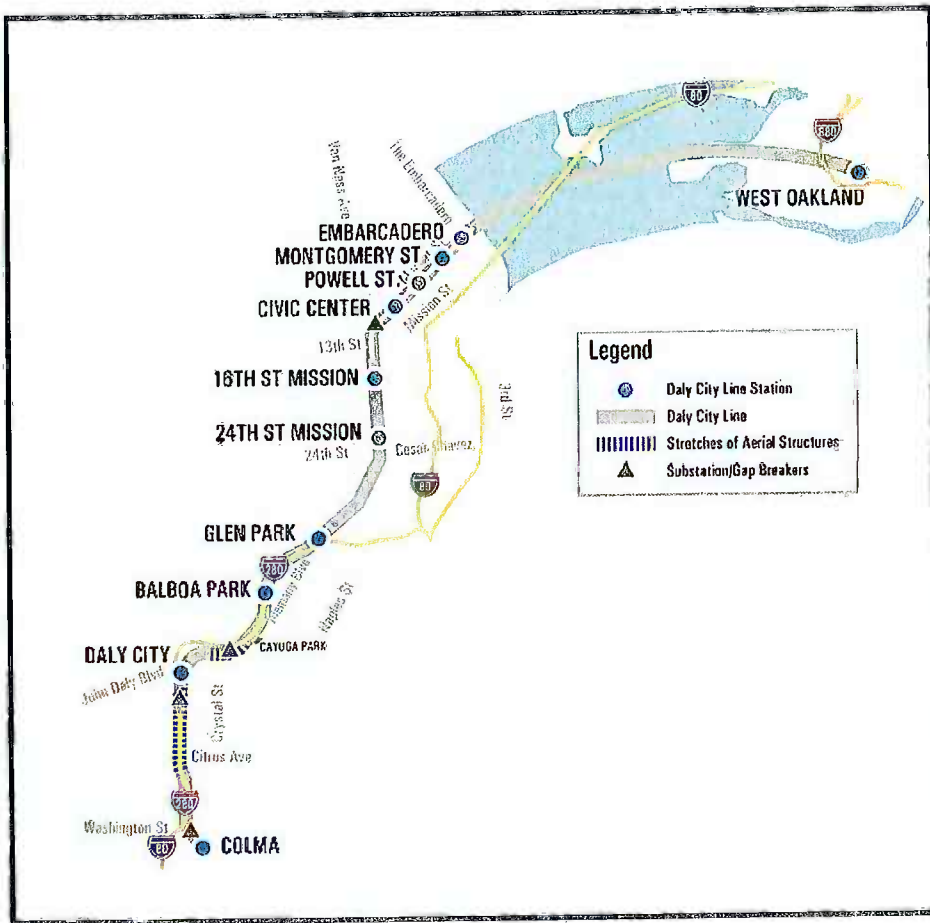


Figure 8: Daly City Line

2.2.5.4. Fremont Line

There are four stretches of aerial structures (traversing or abutting a total of five stations) that include a total of 890 columns and eight street overcrossings on the Fremont Line (see Figure 9).

Oakland/San Leandro – This section largely parallels San Leandro Street in Oakland and San Leandro Boulevard in San Leandro. The section also parallels the Union Pacific Railroad (UPRR). The northern limit of this aerial section is the abutment near 19th Avenue in Oakland. The section traverses the Fruitvale, Coliseum, and San Leandro stations, all of which are elevated. The southern limit of the aerial section is the Bay Fair Station, the north side of which is aerial and south side is at-grade.

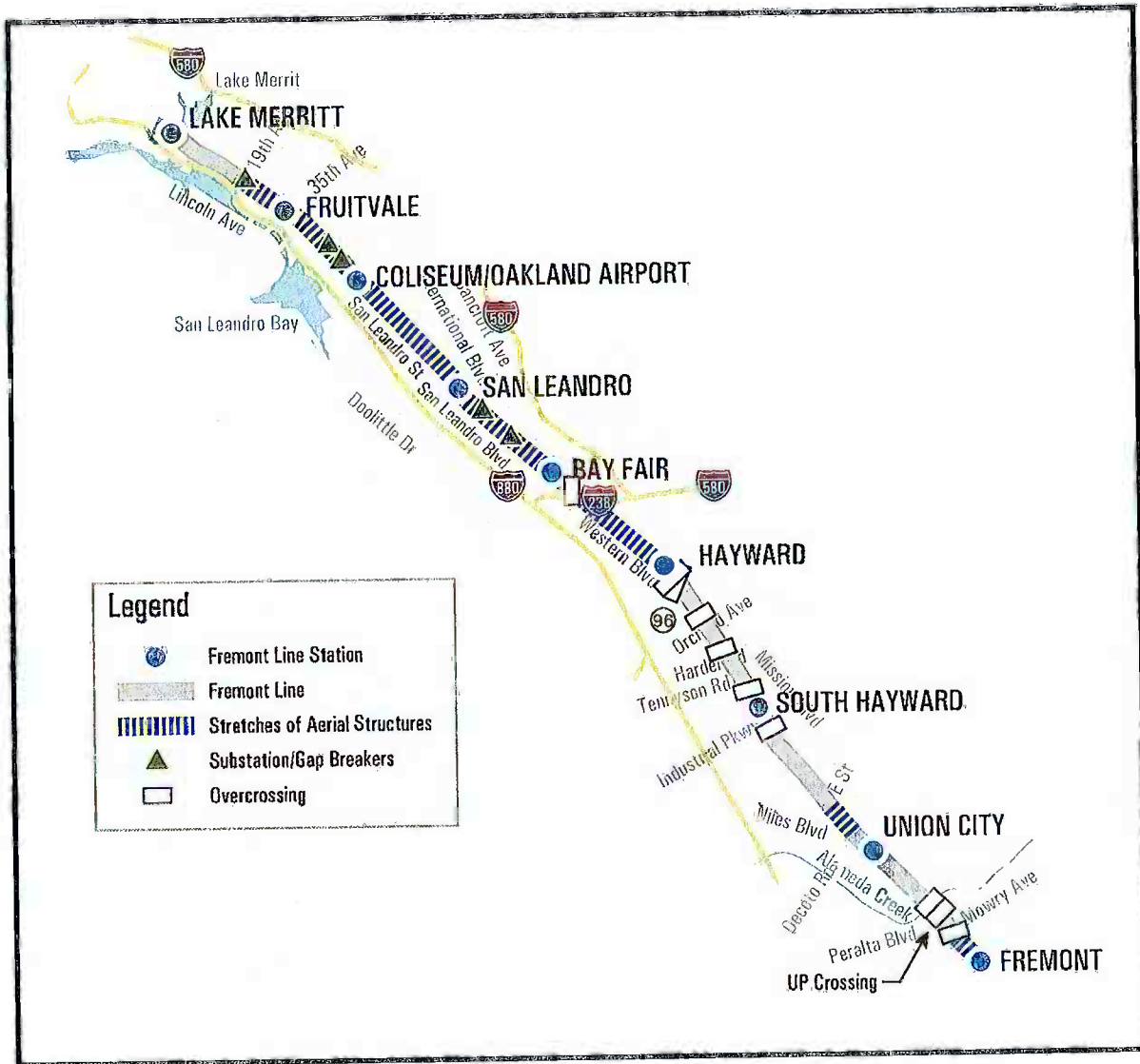


Figure 9: Fremont Line

Hayward – This section largely parallels Western Boulevard and the UPRR in San Lorenzo and Hayward. The northern limit of this section is the abutment near Interstate 238 (I-238). The southern limit is the Hayward Station, the north side of which is aerial and south side is at-grade.

Union City – This section parallels the UPRR Union City. The northern limit of this section is the abutment near E Street. The southern limit is the abutment on the south side of Decoto Road.

Fremont – The northern limit of this section is the abutment approximately 500 feet north of Mowry Avenue. The southern limit is the abutment approximately 200 feet south of Mowry Avenue.

Elevated stations along the Fremont Line include:

- Fruitvale
- Coliseum
- San Leandro
- Bay Fair
- Hayward

Retrofits of overcrossings at the same streets are also needed on the Fremont Line.

- Between the Bay Fair and the Hayward Stations overcrossing may require retrofit.
- Between the Hayward and South Hayward Stations, retrofits may be required.
- A retrofit between the South Hayward and the Union City Station may be needed.
- A retrofit between the Union City and Fremont Stations may need retrofit, and
- The BART Bridge over the UP in Fremont is also included in the analysis.

Potential retrofits of stream crossings on the Fremont Line

- Alameda Creek,
- Dry Creek in Union City,
- Zeile Creek in Hayward.

Up to five substations or gap breakers on the Fremont Line will be temporarily or permanently relocated within the Proposed Project Limits.

2.3. Construction Scenario

The Proposed Project consists of the seismic retrofit of existing BART aerial structures and stations. Construction activities will primarily consist of strengthening existing columns and footings supporting aerial structures and stations. Therefore, construction activities will generally be confined to the area immediately surrounding the aerial structures and at elevated stations. For both the Operability Level and Safety Level of retrofits, the construction zones will typically be within the drip-line (or edge) of the existing BART aerial structures or BART Right-Of-Way. Temporary easements may be required for construction equipment to access construction zones. Construction vehicles will use public roadways to access construction zones. Although a detailed construction plan has not yet been defined, multiple areas within the Proposed Project area will be under construction simultaneously. Contractors will define the sequence of construction activities in consultation with BART.

Construction activities will require the use of haul trucks, excavators, graders, cranes, drill equipment, watering trucks, generators and other typical construction equipment. Pile-driving may be required along portions of the alignment. Pile-driving would be limited to temporary sheet piles for shoring, where necessary.² In areas with sensitive noise receptors, BART may use piles and lagging for temporary support. BART will employ noise reduction measures as necessary to minimize noise impacts and provide advanced public notice, including a hotline for noise complaints.

At locations where the excavations to expose the foundations are deep, vertical shoring may be required. For horizontal foundation enlargement, the excavation is anticipated to extend five to eight feet beyond the footing limits, with the vertical shoring being approximately two feet thick. Therefore, the limits of ground disturbance around each pier to be retrofitted would generally take place within seven to ten feet of the existing footing limits. The limits of the construction area will typically be placed within 15 feet of the excavation for horizontal foundation enlargement and 12 feet for concrete topping only.

Construction activities around aerial structures would displace some parking spaces. Displaced parking would occur around columns and may also occur in some cases for construction access, staging and materials storage. Some sidewalks would be temporarily removed during construction of the retrofit project and then rebuilt at the conclusion of construction. Some bus stops adjacent to BART stations would be temporarily realigned or moved to nearby locations while retrofit work occurs. Traffic would also be re-routed where necessary for access to the piers and would be minimized or avoided through implementation of a construction phasing and traffic management plan developed with the direct participation of BART, Cities or Counties and Caltrans. In addition, the property owners of all businesses adjacent to the construction areas will be notified.

BART will maintain regular service throughout construction.

No permanent alteration to transportation facilities/operations would result from the Proposed Project. All traffic impacts would be temporary and related to construction activities and hauling of excavated material. Retrofit activities would result in lane closures, traffic detours, temporary reduction in parking spaces, and disruption of pedestrian and bicycle circulation. All conditions that could affect traffic would be restored to pre-project conditions at the end of construction. These temporary impacts would be reviewed and approved by the appropriate jurisdictions. Construction activities will be coordinated through BART's community relations department for notifications to surrounding neighborhoods and businesses, including a hotline for construction complaints.

² Sheet piles are sheets of steel used to retain soil.

2.3.1. Construction Durations

The estimated construction duration for each project section as follows:

Fremont Line	5 years
Richmond Line	4 years
Daly City Line	2 years
Concord Line	2 years

The estimated construction duration per aerial structure is approximately six to eight weeks. An additional three to four weeks will be necessary where shear keys are required. At most locations, a series of columns will be worked on simultaneously. Approximately 1,578 columns would be retrofitted.

3. Study Methods

3.1. Environmental Noise and Vibration Basics

3.1.1. Noise Fundamentals and Descriptors

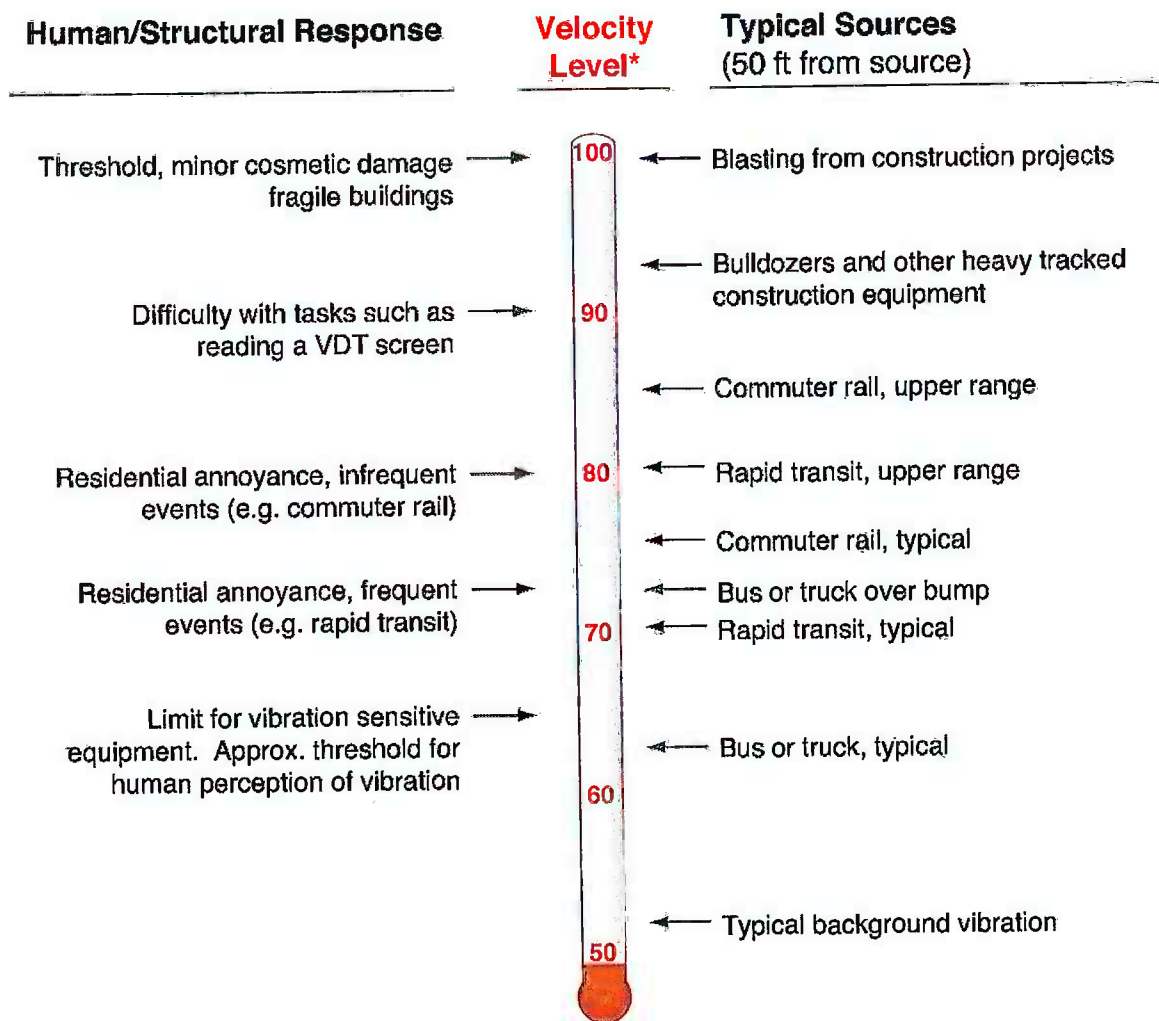
Noise is typically defined as unwanted or undesirable sound, where sound is characterized by small air pressure fluctuations above and below the atmospheric pressure. The basic parameters of environmental noise that affect human subjective response are (1) intensity or level, (2) frequency content and (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 as 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. Figure 6 provides examples of typical noise levels for different sources

Because environmental noise fluctuates from moment to moment, it is common practice to condense all of this information into a single number, called the "equivalent" sound level (L_{eq}). L_{eq} 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).

stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response, which is better related to the average vibration amplitude. Thus, ground-borne vibration from transit trains is usually 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.

Figure 7 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.



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

FIGURE 7 -- Typical Ground-Borne Vibration Levels and Criteria

3.2. Construction Noise Criteria

The BART Design Criteria contain construction noise criteria limiting both continuous and intermittent noise levels due to construction activities. The BART Design Criteria apply to all BART construction activities, including those anticipated in this project. The BART Design Criteria are similar to the Federal Transit Administration (FTA) standards, which are typically applied to transit projects. The Federal Highway Administration (FHWA) noise and vibration protocols were not used for this project because the project is not a Type 1 project as defined in 23 CFR 772.5(h); “construction on new locations or the physical alteration of an existing highway, which significantly changes either the horizontal or vertical alignment or increases the number of through-traffic lanes.” Under State law, BART is not required to comply with certain local land use requirements, including noise standards. Consequently, City ordinances do not define the standards by which impacts are evaluated.

The BART construction noise criteria are presented in terms of the type of noise (continuous or intermittent), the time of day (where daytime is defined as 7 AM to 7 PM daily except Sundays and legal holidays, which fall into the nighttime category), and the land use category of potential sensitive receptors. The criteria are included below for continuous noise (Table 1) and intermittent noise (Table 2).

TABLE 1 -- Criteria for Continuous Construction Noise

Land Use Category	Maximum Allowable Continuous Noise Level, dBA	
	Daytime	Nighttime
Residential		
Single-Family Residential	60	50
Along an Arterial or Multi-Family Residential Area, including Hospitals	65	55
Semi-Residential/Commercial Areas, including Hotels	70	60
Commercial		
At All Times		
Semi-Residential/Commercial Areas, including Schools	65	
Commercial Areas with no nighttime residency	70	
Industrial		
All Locations	80	

Source: BART Design Criteria for Noise (1992)

Note: Noise limits apply at 200 feet from the construction limits or at the nearest affected building, whichever is closer.

TABLE 2 -- Criteria for Intermittent Construction Noise

Land Use Category	Maximum Allowable Intermittent Noise Level, dBA	
	Daytime	Nighttime
Residential		
Single-Family Residential	75	60
Along an Arterial or Multi-Family Residential Area, including Hospitals	75	65
Semi-Residential/Commercial Areas, including Hotels	80	70
Commercial		
At All Times		
Semi-Residential/Commercial Areas, including Schools	80	
Commercial Areas with no nighttime residency	85	
Industrial		
All Locations	90	

Source: BART Design Criteria for Noise (1992)

Note: Noise limits apply at 200 feet from the construction limits or at the nearest affected building, whichever is closer.

3.3. Construction Vibration Criteria

The BART Design Criteria for Noise do not contain criteria for construction vibration. However, FTA has incorporated vibration criteria for construction activities. The FTA construction vibration criteria are presented in terms of the sensitivity of the land use near construction sites. The criteria are included below in Table 3. Based on the land-use survey of the project, there are no buildings that would be in the Category IV, so the vibration criterion for this project would be 0.2 in/sec.

TABLE 3 -- FTA Criteria for Construction Vibration

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

Source: Transit Noise and Vibration Impact Assessment (FTA Report No. FTA-VA-90-1003-06), May 2006

3.4. Construction Noise Assessment Method

Construction noise varies greatly depending on the construction process, type and condition of equipment used, and layout of the construction site. Many of these factors are traditionally left to the contractor's discretion, which makes it difficult to accurately estimate levels of construction

noise. Overall, construction noise levels are governed primarily by the noisiest pieces of equipment. For most construction equipment, the engine, which is usually diesel, is the dominant noise source. This is particularly true of engines without sufficient muffling. For special activities such as impact pile driving and pavement breaking, noise generated by the actual process dominates. Table 4 summarizes some of the available data on noise emissions for equipment that will be used on the Proposed Project. Shown are typical maximum noise levels (L_{max}) at a distance of 50 feet. Although the noise levels in the table represent typical values, there can be wide fluctuations in the noise emissions of similar equipment. Construction noise at a given noise-sensitive location depends on the magnitude of noise during each construction phase, the duration of the noise, and the distance from the construction activities.

Projecting continuous construction noise levels 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). Using the typical sound emission characteristics, as given in Table 4, it is then possible to estimate the daily L_{eq} (or continuous noise level) at various distances from the construction site. The continuous 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 such as those in Table 4, and estimates of noise reduction as a function of distance from the construction site.

Projecting intermittent construction noise levels requires only a construction scenario of the equipment likely to be used. Intermittent noise levels are a function of the maximum noise levels, as shown in Table 4, and of the noise attenuation as a function of distance from the construction site.

TABLE 4 – Typical Construction Equipment Noise Emission Levels

Equipment	Typical Noise Level at 50 ft (dBA)	Equipment	Typical Noise Level at 50 ft (dBA)
Air Compressor	81-85	Grader	83-85
Backhoe	80-83	Hoe Ram	85-90
Chain Saw	85	Impact Wrench	85
Compactor	82	Jackhammer	88-89
Compressor	85-90	Loader	85-88
Concrete Truck	81	Paver	80-89
Concrete Mixer	85	Pile Driver, Impact	101
Concrete Pump	82	Pile Driver, Sonic	96
Concrete Vibrator	76	Pump	80-85
Crane, Derrick	86-88	Rock Drill	98
Crane, Mobile	83-87	Roller	74
Dozer	84-88	Scraper	89
Drill Rig	88	Slurry Machine	91
Dump Truck	84	Slurry Plant	78
Excavator	84	Truck	85-89
Generator	85	Vacuum Excavator	85-88
Gradall	86		

Source: National Cooperative Highway Research Program (1999).

3.5. Construction Vibration Assessment Method

The assessment of construction vibration is based on the maximum vibration levels generated by a specific piece of equipment. Typically, only activities such as pile driving, hoe ramming, or vibratory compacting have the potential to generate vibration levels that would exceed the BART vibration criteria. For this assessment, the only construction equipment with the potential to generate sufficient vibration levels to exceed the FTA criteria are vibratory rolling, which is used to compact pavement and soil and possibly sheet piling, which may be used at Alameda Creek and Daly City. Table 5 summarizes some of the available data on vibration source levels at 25 feet for equipment that will be used on this project. The formula used to calculate the vibration level at a given distance is:

$$L_{(\text{equip})} = L_{(\text{ref})} \times (25/D)^{1.5}$$

Where:

- $L_{(\text{equip})}$ = Vibration level in in/sec at a specific distance
- $L_{(\text{ref})}$ = Reference vibration level in in/sec at 25 feet
- D = Distance from the equipment to the receiver

TABLE 5 -- Typical Construction Equipment Vibration Source Levels

Equipment	Vibration Level at 25 ft
Pile Driver (Impact)	0.64 in/sec (104 VdB)
Pile Driver (Sonic)	0.17 in/sec (93 VdB)
Vibratory Roller	0.21 in/sec (94 VdB)

Source: Transit Noise and Vibration Impact Assessment (FTA Report No. FTA-VA-90-1003-06), May 2006

4. Environmental Setting

This section describes the existing noise environment and the noise and vibration sensitive receptors within the proposed project limits. The primary focus of the noise and vibration analysis is on areas with residential land use which has the most stringent noise criteria and is the most sensitive to construction noise and vibration. The information contained in this section is based on a land-use survey conducted during the week of March 27, 2006 and noise measurements conducted June 1 and 2, 2006. The land use summary below includes all sensitive receptors within 200 feet of the guideway and/or overpasses and stations along each of the line segments.

4.1. Existing Noise Setting

Existing ambient noise levels in the project area were characterized through direct measurements at selected sites along the proposed alignment during the period from June 1 through June 2, 2006. All of the measurement sites were located in noise-sensitive areas, and were selected to represent a range of existing noise conditions along the corridor.

Short-term, ambient noise measurements were conducted at 20 sites, as shown in Table 6. At each of these locations, attended Larson Davis Model 820 portable, automatic noise monitors were used to continuously sample the A-weighted sound level (with slow response), over a 30-minute period. The noise monitors were programmed to record the equivalent sound level (Leq) over the measurement period.

The noise measurement equipment described above conforms to ANSI Standard S1.4 for Type 1 (Precision) sound level meters. Calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST) were carried out in the field before and after each set of measurements using acoustical calibrators.

In all cases, the measurement microphone was protected by a windscreen, and supported on a tripod at a height of 4 to 6 feet above the ground. The microphone was positioned to characterize the noise exposure of the nearest receptors to the BART rail lines (the dominant noise source). The existing noise at all locations is dominated by BART rail operations and traffic on local streets and highways. The highest existing ambient noise levels are at sites where the sensitive receptors are closest to the BART lines or where there is a significant contribution from traffic on local streets or from highways, such as State Highway 24 on the Concord Line.

TABLE 6 – Summary of Existing Ambient Noise Measurement Results

Site No.	Measurement Location Description	Start of Measurement		Measurement Time (min)	Leq (dBA)
		Date	Time		
Fremont Line					
1	1224 Derby Ave, Oakland	6/1/2006	17:00	30	68
2	16356 Elgin Way, San Lorenzo	6/2/2006	11:20	30	62
3	604 Blossom Way, Hayward	6/2/2006	10:30	30	64
4	658 Atherton Pl, Hayward	6/2/2006	9:36	30	64
5	28344 Cole Pl, Hayward	6/2/2006	8:45	30	63
6	33663 12 th St, Union City	6/2/2006	7:55	30	68
7	1560 Skelton Ct, Fremont	6/2/2006	7:00	30	55
8	38533 Vancouver Common, Fremont	6/1/2006	18:20	30	72
Concord Line					
1	1027 Brown Ave, Lafayette	6/2/2006	13:00	30	65
2	1321 Springbrook Rd, Walnut Creek	6/2/2006	13:50	30	64
3	Minert Rd, Pleasant Hill	6/2/2006	14:55	30	70
4	1220 Mesa St, Concord	6/2/2006	15:45	30	69
Daly City Line					
1	80 De Long St, San Francisco	6/1/2006	13:55	30	67
2	406 Niantic Ave, Daly City	6/1/2006	14:50	30	70
Richmond Line					
1	1627 Portola Ave, Richmond	6/1/2006	7:00	30	61
2	2436 Chanslor Ave, Richmond	6/1/2006	8:00	30	64
3	3621 Ohio Ave, Richmond	6/1/2006	9:05	30	55
4	2105 Kearney St, El Cerrito	6/1/2006	10:00	30	72
5	810 60 th St, Oakland	6/1/2006	11:35	30	62
6	766 53 rd St, Oakland	6/1/2006	12:30	30	71

Source: HMMH, 2006.

4.2. Existing Land-Use

4.2.1. Concord Line

The land use along this line is a mix of residential, with both single-family and multi-family land-use, along with commercial land use throughout the project area. Table 7 summarizes the land uses for the Concord Line, for each aerial guideway section, overpass and station that is included in the project.

TABLE 7 --Concord Line Noise and Vibration Sensitive Land Use

Project Location	Sensitive Receptors ¹		Distance to Nearest Sensitive Receptor (ft)
	SF	MF	
Aerial Guideway Sections			
Lafayette West	0	0	300
Lafayette East	4	0	200
Walnut Creek West	8	0	50
Walnut Creek East	0	5	200
Pleasant Hill ²	6	7	100
Overpasses			
Acalanes Rd., Orinda	0	0	600
Dolores Rd., Lafayette	0	0	250
Happy Valley Road, Lafayette	0	0	300
Oak Hill Road, Lafayette	0	0	600
First Street, Lafayette	0	0	450
Pleasant Hill Road, Lafayette	0	0	650
Bancroft Road, Pleasant Hill	4	0	180
Oak Grove Road, Pleasant Hill	6	0	180
Systron Drive, Concord	0	0	320
Stations			
Orinda	0	0	1200
Lafayette	0	0	550
Walnut Creek	0 ³	0 ³	-- ³
Pleasant Hill	0 ³	0 ³	-- ³

1. Noise and vibration sensitive receptors within 200 feet of the guideway, overpass or station. SF = Single-Family Residences, MF = Multi – Family Residences

2. There is also a hotel located within 200 feet of this guideway section.

3. These stations are located along the aerial structures and are therefore included in the aerial guideway sections.

4.2.2. Richmond

The land use along this line is primarily residential, with a mix of both single-family and multi-family land-use, with some commercial land-use throughout the corridor. Table 8 summarizes the land uses for the Richmond Line, for each aerial guideway section, overpass and station that is included in the project.

TABLE 8 --Richmond Line Noise and Vibration Sensitive Land Use

Project Location	Sensitive Receptors ¹		Distance to Nearest Sensitive Receptor (ft)
	SF	MF	
Aerial Guideway Sections			
Richmond	10	0	120
El Cerrito/Albany/Berkeley			
North of El Cerrito del Norte Station	10	5	70
El Cerrito del Norte Station – El Cerrito Plaza Station	180	26	70
South of El Cerrito Plaza Station	330	2	80
Oakland/Berkeley ²	100	45	80
Overpasses			
Barrett Avenue, Richmond	0	6	180
MacDonald Avenue, Richmond	8	0	180
37 th Street, Richmond	8	0	80
Stations³			

1. Noise and vibration sensitive receptors within 200 feet of the guideway, overpass or station. SF = Single-Family Residences, MF = Multi – Family Residences
2. There is also a hospital located within 200 feet of this guideway section.
3. The El Cerrito del Norte and El Cerrito Plaza stations are located along the aerial structures and are therefore included in the aerial guideway sections.

4.2.3. Daly City

The land use along this line is primarily residential in San Francisco, with both single-family and multi-family land-use, and primarily commercial in Daly City, with a few residences. Table 9 summarizes the land uses for the Daly City Line, for each aerial guideway section and station that is included in the project.

TABLE 9 --Daly City Line Noise and Vibration Sensitive Land Use

Project Location	Sensitive Receptors ¹		Distance to Nearest Sensitive Receptor (ft)
	SF	MF	
Aerial Guideway Sections			
San Francisco	25	25	80
Daly City	5	0	180
Overpasses²			
Stations³			

1. Noise and vibration sensitive receptors within 200 feet of the guideway, overpass or station. SF = Single-Family Residences, MF = Multi – Family Residences
2. There are no overpasses located on this line.
3. The Daly City Station is located along the aerial structure and is therefore included in the aerial guideway section.

4.2.4. Fremont Line

The majority of the land use along the southern section of this line is residential, with a mix of single-family and multi-family. The northern section is primarily commercial and industrial, with some areas of residential land-use. Table 10 summarizes the land uses for the Fremont Line, for each aerial guideway section, overpass and station that is included in the project.

TABLE 10 –Fremont Line Noise and Vibration Sensitive Land Use

Project Location	Sensitive Receptors ¹		Distance to Nearest Sensitive Receptor (ft)
	SF	MF	
Aerial Guideway Sections			
Oakland/San Leandro			
Lake Merritt Station – Fruitvale Station	6	0	80
Fruitvale Station – Coliseum Station	12	0	40
Coliseum Station – San Leandro Station	107	0	90
San Leandro Station – Bay Fair Station	111	18	40
Hayward	265	12	50
Union City	77	0	40
Fremont	5	7	70
Overpasses			
Ashland Avenue, San Lorenzo	5	0	110
D Street, Hayward	0	12	120
Jackson Street, Hayward	0	4	170
Orchard Avenue, Hayward	5	8	70
Harder Road, Hayward	8	0	160
Tennyson Road, Hayward	10	0	150
Industrial Parkway, Hayward	0	0	500
Alameda Creek	0	0	240
Peralta Avenue, Fremont	10	0	120
Stations			

1. Noise and vibration sensitive receptors within 200 feet of the guideway, overpass or station. SF = Single-Family Residences, MF = Multi – Family Residences
2. The Fruitvale, Coliseum, San Leandro, Bay Fair and Hayward Stations are located along the aerial structures and are therefore included in the aerial guideway sections.

5. Conclusions/Findings

5.1. Construction Noise

5.1.1. Continuous Noise

Tables 11 and 12 are worst-case noise projections for typical equipment rosters for this type of construction. For the calculations it is assumed that all the equipment is located at the geometric center of the construction work site. Based on this scenario, a maximum 8-hour Leq of 81 dBA is projected at a distance of 50 feet from the work site for the safety design scenario, and a maximum 8-hour Leq of 82 dBA at 50 feet from the work site for the operability design scenario. At 200 feet (the limit in the BART continuous noise criteria), this would be equal to a maximum 8-hour Leq of 69 dBA for the design scenario and a maximum 8-hour Leq of 70 dBA for the operability design scenario. The two design scenarios have similar projected noise levels from construction activities. The one dBA difference between the two scenarios is generally not perceptible to human hearing outside of a controlled environment. Because of this, the impact assessment is essentially identical for each scenario.

These estimates suggest that the potential for construction noise impact will be minimal for commercial and industrial land use beyond 200 feet for both construction scenarios. For residential land use, the potential for temporary construction noise impact would exist under both construction scenarios without the inclusion of noise control measures.

The calculations in Tables 11 and 12 are worst-case scenarios and do not assume any noise control measures or any limits on the contractor regarding how much noise can be made. However, as is typical with construction in a dense urban setting with nearby residential land-use, noise control measures will be built into the specifications for the contractors to ensure that the construction noise meets the BART limits. Details on specific measures are included in Section 6.

TABLE 11 -- Safety Design Scenario Noise Assessment

Equipment Item	Typical Maximum Sound Level at 50 ft (dBA)	Equipment Utilization Factor (%)	Leq (dBA)
Backhoe	80	10%	70
Concrete Mixer	85	5%	72
Crane, Mobile	83	5%	70
Dump Truck	84	10%	74
Forklift	80	10%	70
Loader	85	10%	75
Truck	85	10%	75
Vibratory Roller	85	5%	72
Continuous Noise Level at 50 ft			82
Continuous Noise Level at 200 ft			70

Source: HMMH, 2006.

TABLE 12 -- Operability Design Scenario Noise Assessment

Equipment Item	Typical Maximum Sound Level at 50 ft (dBA)	Equipment Utilization Factor (%)	Leq (dBA)
Auger Drill Rig	85	5%	72
Backhoe	80	10%	70
Concrete Mixer	85	5%	72
Crane, Mobile	83	5%	70
Dump Truck	84	10%	74
Forklift	80	10%	70
Loader	85	10%	75
Truck	85	10%	75
Vibratory Roller	85	5%	72
Continuous Noise Level at 50 ft			82
Continuous Noise Level at 200 ft			70

Source: HMMH, 2006.

5.1.2. Intermittent Noise

There is the potential for impact from intermittent construction noise sources for the worst-case scenario is at single- and multi-family land use within 100 feet of the alignment. Noise mitigation will be included to limit continuous noise, as discussed in Section 6.

5.2. Construction Vibration

The only types of equipment with the potential to cause vibration impact would be the vibratory roller and piling. However, vibration levels generated by a vibratory roller or sonic pile driving would not exceed the FTA criterion of 0.2 in/sec at 25 feet. Based on observations of the sections where construction is to occur, there are no buildings within this distance of the BART structures.

At Alameda Creek and Daly City, where there is the potential for sheet piling, the sensitive receptors are at distances greater than 180 feet, beyond the distance where vibration impact would occur.

6. Noise Mitigation

Temporary noise during construction has the potential of being intrusive to residents near the construction sites. Because the worst-case noise levels projected in Section 5 are higher than the criteria set by BART, noise mitigation will be carried out as described below.

BART will require the contractors to comply with BART noise standards by minimizing the noise caused by construction activities, providing working machinery and equipment fitted with efficient noise suppression devices and monitoring noise levels during work operations. The contractors will be required to submit a plan to BART detailing how they will meet the criteria at each location where work is to be performed. This approach allows the contractor flexibility to meet the noise limits in the most efficient and cost-effective manner.

With the inclusion of the appropriate noise mitigation measures, the noise levels at all locations will meet the BART noise criteria. Noise mitigation measures that will be applied as needed to meet the noise limits include the following:

Avoid nighttime construction (10 PM to 7 AM) in residential neighborhoods. If nighttime construction is required, BART will take every measure to minimize the noise to the surrounding community, including potentially rescheduling nighttime construction to daytime weekends, single-tracking limited sections of the alignment in the vicinity of proposed nighttime construction to allow daytime construction with limited operations, providing temporary noise shrouds, and if necessary providing hotel rooms for residents who, after implementation of other mitigation measures, would still be exposed to continuous or recurring intermittent nighttime noise in excess of BART standards. Provide advance public notice regarding construction activities, including a hotline for noise complaints.

Prohibit construction equipment that does not meet the lower BART noise emission limit (85 dBA at 50 feet).

Where feasible, use electric-powered equipment instead of diesel equipment and hydraulic tools instead of pneumatic tools.

At Alameda Creek and Daly City, if piling occurs, the use of vibratory or pushed piles should be investigated to limit the noise levels, if geological conditions permit their use.

Line hopper storage bins and chutes with sound-dampening material.

Employ effective intake and exhaust mufflers on all internal combustion engines and compressors.

Use specially quieted equipment with enclosed engines and/or high-performance mufflers.

Locate stationary construction equipment as far as possible from noise-sensitive sites.

Construct noise barriers, such as temporary walls or piles of excavated material, between noisy activities and noise-sensitive receivers.

Re-route construction-related truck traffic along roadways that will cause the least disturbance to residents.

Perform noise monitoring during construction to verify compliance with the BART limits.

The amount of noise reduction provided by each of these measures varies, and is dependent on many variables at each location. However, noise control measures should be able to achieve 10-20 dB of noise reduction from construction activities.

With the incorporation of the appropriate noise control measures, there will be no impacts from construction-generated noise. To provide added assurance, a complaint resolution procedure shall be put in place to rapidly address any noise problems that may develop during construction.

7. References

Transit Noise and Vibration Impact Assessment (FTA Report FTA-VA-90-1003-06, May 2006);

BART Design Criteria for Noise, 1992.

8. Preparers

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