Government of the District of Columbia

Department of Transportation

FINAL

CSX Virginia Avenue Tunnel

Vibration Monitoring Review

DCKA-2016-C-0500

Prepared For:

DDOT

Prepared By:

CH2M

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Executive Summary

The Virginia Avenue Tunnel project involves the replacement of a 100-year-old masonry arch railroad tunnel with two new reinforced concrete box tunnels. The project is in Washington, DC immediately below Virginia Avenue SE from 2nd Street to 11th Street. The purpose of this report is to provide a review of the vibration monitoring program implemented by CSX for the project. Vibration concerns have been raised by the surrounding community, particularly since trains began operating in the new Phase 1 tunnel in December 2016. This report provides:

1. Review of the CSX vibration analysis included in the Final Environmental Impact Statement (EIS);
2. Summary of community complaints and correspondence;
3. Overview of the CSX supplemental monitoring program; and
4. Recommendations and next steps.

There are no statutory or regulatory limits established for vibration impacts due to freight train operations. Therefore, the EIS used guidelines developed by the Federal Transit Administration (FTA) for transit projects to assess potential vibration impacts of this freight rail project. The EIS concluded that vibration from train operations would increase with trains operating in the new tunnel, but would not exceed the human annoyance criteria established by CSX in the EIS.

However, after trains began operating in the first new tunnel, CSX and the District Department of Transportation (DDOT) received complaints from residents concerning increased vibration that they attributed to CSX operations. These complaints were expressed to DDOT, CSX, the Advisory Neighborhood Commission, the Ward 6 City Councilmember, and the US Department of Transportation. CSX did not respond to DDOT requests to confirm whether or not trains were present during the times residents reported vibrations.

In response to the community complaints, CSX installed engineering mitigation measures to reduce vibration in the tunnel and collected supplemental vibration monitoring measurements that isolated vibration impacts from train operations. The supplemental monitoring collected data from 25 train pass-bys and reported that average vibration levels did not exceed the human annoyance criterion for any of the pass-bys.

Key takeaways and recommendations from this review include:

1. It is not clear how much vibration has increased since trains began operating in the new tunnel. However, *it is probable that train operations are causing perceptible vibrations reported by residents* near the tunnel.
2. The Construction Monitoring system installed by CSX was set up to monitor vibration from construction activities and does not provide data that is useful for assessing human annoyance from rail operations.
3. The average vibration levels reported by CSX for the supplemental monitoring do not exceed the criteria identified in the EIS. However, there are a number of questions that were not answered with the supplemental monitoring summary provided by CSX.
4. CSX should prepare a formal report outlining the methodology, justification, and conclusions of the supplemental monitoring program.
5. CSX should conduct a follow-up monitoring program after construction is complete. This program should look at additional locations and include monitoring on the top floor of residences.

Table of Contents

1. Introduction

The Virginia Avenue Tunnel project involves the replacement of a 100-year-old masonry arch railroad tunnel with two new reinforced concrete box tunnels. The tunnel is immediately below Virginia Avenue SE from 2nd Street to 11th Street. CSX, the tunnel owner, completed an Environmental Impact Statement (EIS) to meet the requirements of the National Environmental Policy Act (NEPA). The Federal Highway Administration (FHWA) was the lead agency on the EIS and a final Record of Decision was issued on June 5, 2014.

1.1. Vibration Summary

One of the topics assessed in the EIS was potential vibration impacts at adjacent properties caused by construction activities and subsequent train operations in the new reinforced concrete box tunnels. There are no statutory or regulatory limits established for vibration impacts from freight train operations, so the EIS used guidelines published by the Federal Transit Administration (FTA) to assess potential vibration impacts. CSX performed vibration monitoring and analysis to document existing vibration levels in the project area, including vibration levels during a train pass-by. The analysis estimated potential future vibrations from train operations and predicted that the criteria established by the FTA would be satisfied. CSX agreed to perform vibration monitoring throughout construction to mitigate against potential structural damage from construction activities.

1.2. Tunnel Construction

Since construction began in May 2015, CSX has been performing continuous vibration monitoring at eight locations in the corridor to ensure that vibrations from construction activities do not exceed the established thresholds. They provide monthly summary reports of the construction vibration measurements to the public.

In December 2016, CSX began running trains in the first new tunnel. Since that time, CSX and DDOT have received numerous complaints from front row residents (those closest to the tunnel) and others in the community about increased vibrations that residents attribute to train operations, not to construction activities.

1.3. Mitigation and Monitoring of Vibration Due to Rail Operations

In response to the public complaints, CSX implemented a number of vibration minimization measures in the new tunnel, and they collected supplemental operational monitoring measurements. The operational monitoring utilized more sophisticated equipment and analysis than the construction vibration program, which enabled CSX to isolate the vibrations resulting from train pass-bys.

1.4. Report Content

This report was prepared to provide a review of the CSX vibration monitoring program. It begins with an overview of the EIS and the relevant vibration measurements and criteria, reviews the findings reported by CSX of the supplemental vibration monitoring, and provides comments and recommendations for next steps that can be taken by DDOT or CSX. This report does not include any new data collection or new analysis of vibration data. It is not within the scope of this report to determine the causes of vibration reported by the residents nor to determine appropriate mitigation measures.

The remainder of this report is divided into the following sections:

2. EIS Vibration Assessment

3. Summary of Community Complaints and Correspondence
4. CSX Supplemental Mitigation and Monitoring
5. CSX Construction Monitoring Program
6. Key Takeaways
7. Recommendations and Next Steps

2. EIS Vibration Assessment

The vibration assessment presented by CSX in the EIS identified the criteria for vibration measurement and impact determination, analyzed the proposed project impacts, and proposed mitigation to address those impacts.

Vibration concepts, measurements and analysis techniques for transit projects are discussed by the FTA in the *Transit Noise and Vibration Impact Assessment* (FTA-VA-90-1003-06, May 2006) guidance manual (the FTA Manual). The FTA Manual provides background information on the science and measurement of vibration, establishes analysis requirements, and provides guidance on vibration limits for transit projects. Though not fully applicable to freight projects such as the Virginia Avenue Tunnel, no similar federal guidance document exists for freight railroads. Therefore, the Virginia Avenue Tunnel EIS used the FTA vibration limits.

2.1. Vibration Measurement

Vibration can be described in many ways using various metrics. The three most common are listed below and shown schematically in Exhibit 1. Each describe the same vibration signal, but using different metrics.

- Peak Particle Velocity (PPV) is measured in inches per second. It is "the maximum instantaneous positive or negative peak of the vibration signal" (FTA p. 7-3). Because particles typically vibrate around a fixed point, the PPV oscillates from positive to negative values. PPV is typically used to assess building damage.
- Root Mean Square Velocity (RMS) is also measured in inches per second. The FTA Manual notes that PPV is "appropriate for measuring building damage, [but] it is not suitable for evaluating human response. It takes some time for the human body to respond to vibration signals. In a sense, the human body responds to an average vibration amplitude" (FTA p. 7-3). If one were to compute the standard arithmetic average of the velocity amplitude it would be zero, therefore the root mean square

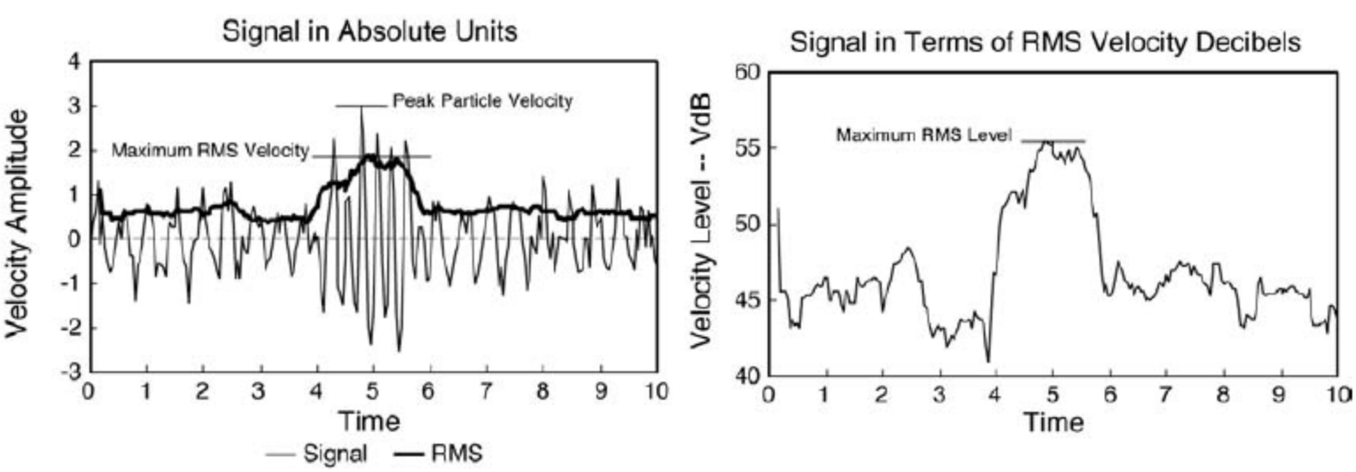

Exhibit 1. Different Methods of Describing Vibration Signal (Source: FTA 2006, Figure 7-2)

(RMS) amplitude is used. Squaring the amplitude ensures all values are positive. The average is typically calculated over a one-second period.

- Vibration Velocity Level (L_v or VdB) is also used to report vibration levels and is the RMS vibration expressed in decibel notation rather than inches per second. In some instances, this has advantages as "decibel notation acts to compress the range of numbers required to describe vibration" (FTA p. 7-4).

The FTA Manual uses the decibel notation (VdB) to discuss the human response to vibration. Exhibit 2 shows typical levels of ground-borne vibration and the approximate human response on a scale from 50 VdB (typical background vibration) to 100 VdB. The threshold of human perception is around 65 VdB (FTA p. 7-5). The manual notes that "there has been relatively little research into human response to vibration," and that "complaints have been associated with measured vibration that is lower than the perception threshold" (FTA p. 7-6). FTA Table 7-1 shows 75 VdB as the "approximate dividing line between barely perceptible and distinctly perceptible." The table also notes that "many people find transit vibration at this level annoying."

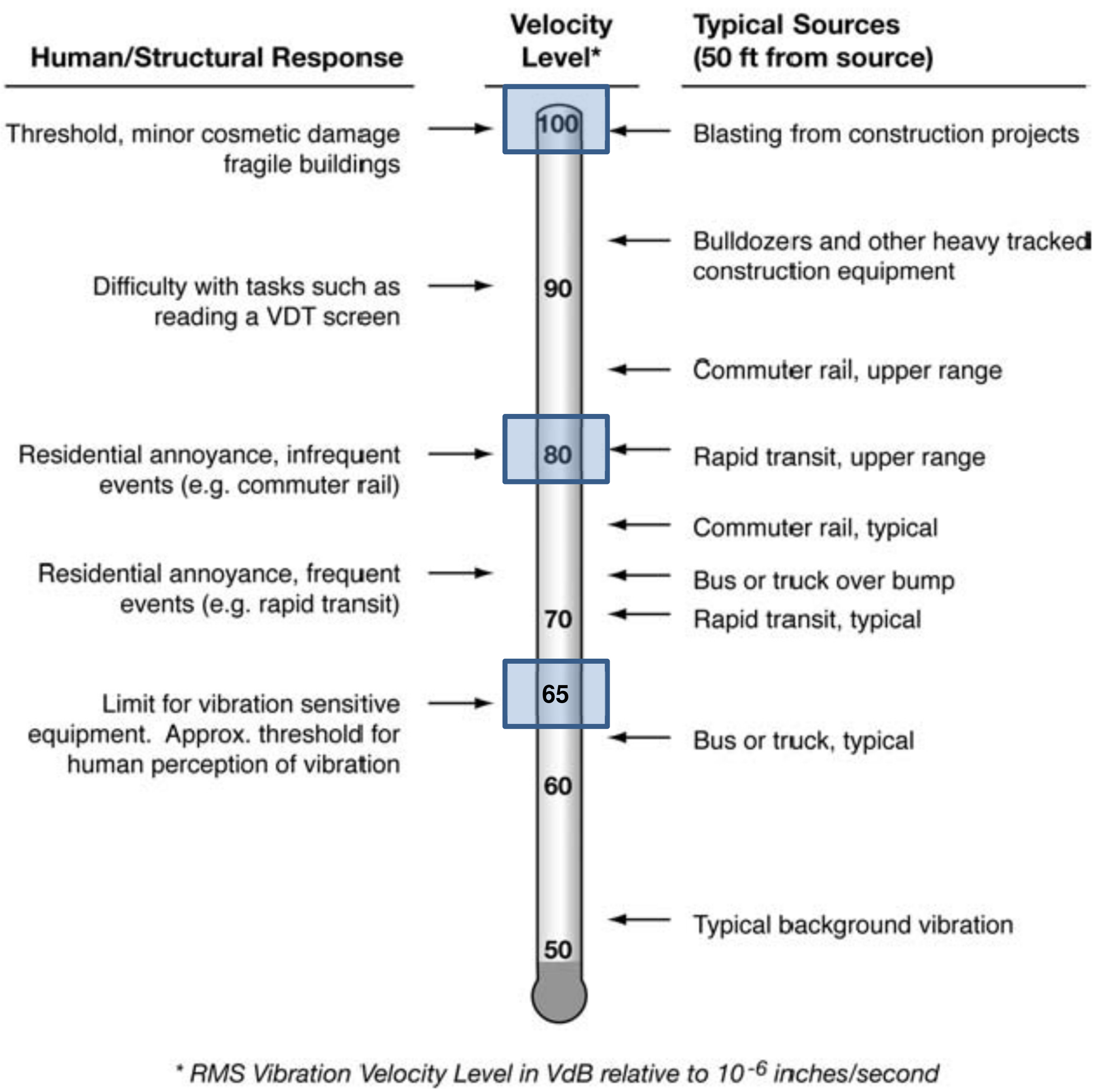

Exhibit 2. Typical Levels of Ground-Borne Vibration (Source: FTA 2006, Figure 7-3)

2.2. Vibration Criteria

The FTA Manual establishes operational vibration impact criteria for transit projects for three land use categories and three activity levels (FTA Table 8-1). Acceptable vibration levels increase as land use categories go from more sensitive to less sensitive, and as activity levels go from frequent to less frequent. The acceptable limit ranges from 65 VdB to 83 VdB. For the Virginia Avenue Tunnel project, the EIS identified the land use category for front row residences as *Category 2: Residences and buildings where people normally sleep*; and identified the activity category as *Infrequent Events (fewer than 30 events per day)*. The relevant human annoyance criterion for Category 2 land uses and Infrequent Events established by FTA is **80 VdB** (0.040 in/sec). This vibration level would be expected to be perceptible. However, because of the low frequency of events, it would not rise to the level of an impact that needs to be mitigated. Key vibration levels for human perception, human annoyance, and structural damage are highlighted graphically on Exhibit 2.

2.3. EIS Vibration Analysis Report

CSX considered vibration impacts from construction activities and train operations in the EIS. A Vibration Analysis Report (Attachment 1) was prepared and included as Appendix F to the EIS. As part of the report, CSX collected vibration measurements at twelve sites, and specifically identified train pass-bys in the data. Based on the vibration propagation seen in the study, the report predicted construction and operations vibration levels. The report predicted an increase in operations vibrations from 71 VdB to 78 VdB at the front row residences. This predicted vibration level was based on two trains passing at the same time, each going 40 mph. While these vibration levels are considered perceptible, the 80 VdB criterion was not predicted to be exceeded, and operational monitoring was not included as a mitigation measure in the EIS.

For construction related activities, CSX committed to conduct pre-construction surveys, to implement a vibration monitoring program to measure vibration during construction, and to reimburse homeowners for any damage caused by construction activities.

2.4. Predicted Vibration Impacts

Vibration impacts were discussed in the Vibration Analysis Report and in Section 4.7 and Section 5.7 of the EIS. The findings of the Vibration Analysis Report were used to calculate the outer limit of vibration that would reach the 80 VdB human annoyance threshold, measured from the centerline of the track. The human annoyance impact distance for two trains operating at 40 mph was 30 feet (EIS Table 5-16). The distance from the track centerline to the face of the building is reduced from 79 feet to 42 feet at the closest point (Exhibit 3). This corresponds to a decrease from 57 feet to 30 feet from the outside edge of the tunnel. Since the human annoyance impact distance was less than the distance from the track centerline to the closest front row residence, the EIS concluded that vibration impacts from train operations would not exceed the referenced limits and that no operational mitigation was required.

2.5. Review of EIS Analysis

The EIS for the project was prepared by CSX and approved on June 5, 2014 by DDOT and FHWA. A review of the EIS specific to vibration thresholds, impacts, and mitigation identified the complexity of the development and application of the impact thresholds. Because no statutory vibration impact thresholds are established for freight projects, the EIS explains the rationale for the selection of thresholds based on the FTA Manual. Two assumptions in the analysis potentially led to the selection of a threshold criterion for human annoyance that was higher than if alternative assumptions were made.

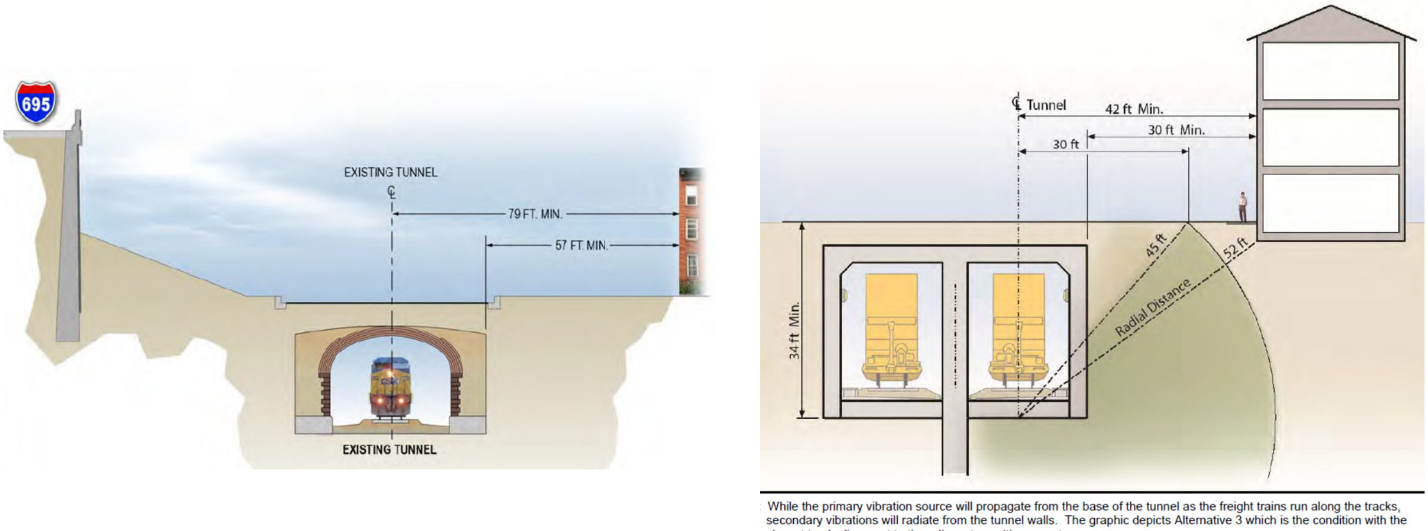

Exhibit 3. Comparison of Tunnel Offset from Closest Structure (Source: Vibration Analysis Report, Figure 1-4 and 5-1)

2.5.1. Use of "Many-Events Limit" for Freight Rail Car Pass-By

In discussion of the application of vibration impacts for freight trains, the FTA Manual (Section 8.1.3) differentiates between vibration during the locomotive pass-by and vibration during the rail car pass-by. It states that the "few-event criterion" is appropriate for the short-term locomotive vibration when there are fewer than 30 events per day, but that the "many-event limits" should be used for the rail car portion of the pass-by, which can last several minutes. Using the many-events limit, the appropriate criterion during the rail car portion of a pass-by would be 75 VdB. The 80 VdB limit would still be appropriate for the locomotive portion of the pass-by. The Vibration Analysis Report did not differentiate locomotive vibration from rail car vibration, so it cannot be determined if the estimated 78 VdB vibration would be associated with the 80 VdB limit or the 75 VdB limit appropriate for the current number of trains.

2.5.2. Potential Increase in Number of Freight Trains

The increased capacity provided by the new tunnel could increase freight traffic to more than 30 trains per day. Data provided by CSX for the Long Bridge Project public meeting on May 16, 2017 indicate that CSX is currently running 18 trains per day across Long Bridge and through the Virginia Avenue Tunnel. The presentation also noted that CSX may increase the number of trains per day to 42 by 2040. This would move into the Occasional Events category (30 to 70 events per day), and lower the criterion for the locomotive pass-by from 80 VdB to 75 VdB.

3. Summary of Community Complaints and Correspondence

CSX and DDOT have received vibration complaints from residents, including front row residents in the 300 block of Virginia Avenue, and residents as far as two blocks away since trains began running in the new tunnel. Residents attribute the vibrations to the train traffic in the new tunnel, which has brought the vibration source closer to their homes (See Exhibit 3).

3.1. Resident Complaints

Residents have reported feeling the house shake, being awakened at night, seeing water vibrate in a glass, and having to frequently straighten pictures hanging on the wall. Some of the specific comments and correspondence include:

- Andrew Shields, a front-row resident, copied DDOT on email correspondence with CSX that started on March 15, 2017.

- On May 10, 2017, Ward 6 Councilmember Charles Allen wrote to DDOT Director Leif Dormsjo (Attachment 2) requesting that DDOT review, investigate and evaluate vibrations and potential impact to property. DDOT sent a response on May 23 (Attachment 3) that outlined efforts to review and improve the CSX monitoring program.
- On May 12, 2017, DDOT received an email from Meredith Fascett, the Advisory Neighborhood Commissioner for this neighborhood. The email provided detailed questions related to vibration impacts, the EIS analysis and the CSX vibration monitoring program. Responses to this email are included in Attachment 4.
- Ms. Fascett provided emails and other documentation of reported vibration incidents from her constituents, including specific dates and times when they have felt vibrations. Some of these reported times are included in Attachment 4. One resident logged the date and time of over 300 instances when he reported feeling vibration from a train between May and September 2017. CSX has declined to confirm that trains were operating in the tunnel at the reported times.
- Residents have reported that vibration is more noticeable on upper floors of their houses. This could indicate vibration amplification due to resonance in the building floors, walls and ceilings. The FTA Manual states that vibration generally reduces as it propagates through a building, but also notes that amplification due to resonances can increase vibration. Reductions are estimated as -2 VdB per floor for propagation. Increases can be as much as +6 VdB through a building, but amplification varies greatly depending on the type of construction. For planning purposes, FTA indicates that these factors can be considered to cancel each other out (FTA Table 10-1 and p. 10-11).
- Residents have noted that the intensity of the vibration has changed over time. It seemed to decrease in late May and early June. During this timeframe, CSX reported that they increased the depth of ballast material in the tunnel, and that they installed friction modifiers on the track surface in an effort to mitigate the reported vibration.

3.2. DDOT Coordination: Site Visits

Mr. Kyle Ohlson of DDOT and Mr. Marlon Smoker of CH2M visited the homes of two front row residents on three separate occasions to observe any noticeable vibration or noise during a train pass-by. No monitoring equipment was used during these visits. The visits occurred for one and a half to two hours on the morning of Tuesday September 26, Wednesday September 27 and Saturday September 30. A total of four trains passed through the tunnel during these times. During each visit, a spotter was located to confirm a train pass-by.

On Tuesday and Wednesday, the observers sat in the fourth floor (top floor) of 323 Virginia Avenue. The owners reported that vibrations were more noticeable on the upper floors. On both days, a train was confirmed in the tunnel, but the observers did not feel any vibrations in the home. Both trains were reported to be carrying primarily single-stack containers.

On Saturday, the observers sat in the first floor of 339 Virginia Avenue. Two trains were confirmed to pass through the tunnel. The first train was reported to carry single-stack containers. The second train had a mix of over height box cars, tank cars and trash cars. During the second pass-by, the observers moved to the 3rd floor (top floor).

Based on the Saturday visit, Mr. Smoker reported that:

> "I would not say that I felt vibration from either train, but I clearly heard both of them (on the ground floor and upstairs). In both cases, I could hear the locomotive pass by, and then a number of cars with wheel flats that followed (a rhythmic ka-thunk, ka-thunk

sound). The sound was distinctive enough that I would have heard it above most background noise. It was similar to what I have heard when standing by the tracks during a pass-by, but significantly muffled."

Also based on the Saturday visit, Mr. Ohlson reported that:

> "From my perspective, with the first train passage, I could distinctly feel and hear the locomotives pass, followed by a less intense vibration and audible rumble through the end of the train. The exceptions were cars with out-of-round wheels, which were felt and heard. The second train was less noticeable. I could feel and hear the locomotives pass, but to a much lesser degree compared with the first train. There was a faint audible rumble through the end of the train, and no noticeable vibration."

3.3. U.S. DOT and FHWA Coordination

Mr. Scott Faulk, a Transportation Industry Analyst in the Office of the Secretary at the US Department of Transportation was copied on certain resident emails. He requested information from Mike Hicks, the Environmental Manager at the DC Division Office of FHWA who was responsible for the EIS process.

On May 10, 2017 Mr. Hicks sent a letter to Mr. William Parry of CSX (Attachment 5). The letter outlines the findings and commitments made in the EIS. Key statements from the letter include:

> "Until an investigation is undertaken to definitively determine the source of vibration, the referenced complaints serve as anecdotal evidence of an impact that was dismissed on numerous occasions during the environmental phase of the project based on the analysis performed by the CSX consultant team."

> "As a result of CSX's analysis and subsequent determinations regarding train operations during the VAT reconstruction, there were no mitigations provided for vibration impacts or effects that cause human annoyance either during construction activities or post construction activities because CSX definitively concluded there would be no vibration impacts in excess of acceptable thresholds."

> "Given the noted uncertainty and until it is proven that adjustments to the technical report analysis are not required, as a minimum measure during the interim, **it may be prudent for CSX to reduce the speed of trains transiting the tunnel during the VAT reconstruction.**" (Emphasis in original)

> "**[M]itigation will be required** if the source of vibration causing annoyance complaints in the community adjacent to the project is due to the VAT reconstruction." (Emphasis in original)

The letter does not establish required additional investigation, nor does it provide detail of potential mitigation.

CSX sent a response to Mr. Hicks on June 6 (Attachment 6). This letter outlined the operational monitoring that CSX planned to undertake. The letter stated that the data would be collected by June 10, and that the analysis would take another 3 to 4 weeks. In the letter, CSX identified the vibration minimization measures that they had already or would be installing.

Amec/Foster Wheeler, the CSX vibration monitoring consultant, sent a follow-up letter to FHWA on September 19 (Attachment 7). The letter stated that the results of the supplemental vibration measurements showed that "all train pass-by events are consistently below the FTA criteria for freight rail vibration related to human annoyance as part of the VAT project's Final EIS."

3.4. CSX Communication

On May 12, 2017 CSX released the following statement on the project website and through their social media accounts.

> ***CSX Investigating Vibration Reports***
>
> *CSX has received reports from some nearby residents that they are experiencing elevated levels of vibration in their homes. While there are no indications that these vibrations present a safety risk to these residents or to anyone in the community, we take these reports very seriously and want to update you about what we are doing in response.*
>
> *From the outset of the Virginia Avenue Tunnel project, we have closely monitored construction vibration levels. Our monitoring system provides real-time alerts to construction managers, notifying them of any instances in which the federally-approved vibration parameters have been exceeded.*
>
> *Upon receiving the reports from neighbors, we immediately began investigating whether train operations are causing vibration impacts. Our investigation is ongoing, and we will share information as it becomes available. In conducting our investigation, we will continue to work closely with the Federal Highway Administration and the District of Columbia Department of Transportation to address residents' concerns.*
>
> *Thank you for your patience and understanding. We remain committed to ensuring the safety of residents and workers, limiting any impact to neighbors, and leaving a great neighborhood even better than we found it.*

4. CSX Supplemental Mitigation and Monitoring

In response to the resident complaints, CSX implemented engineering mitigations and collected supplemental vibration monitoring measurements to focus on vibrations from rail operations. In a meeting with DDOT on June 1, 2017, CSX reported the following:

- CSX made modifications to the track in the tunnel intended to reduce vibration levels, including installation of friction modifiers on the track surface, and installation of additional ballast material beneath the rails. CSX thought it was prudent to proceed with these measures even though they would not be able to measure their effectiveness.
- Operating speed of trains in the new tunnel is 25 mph, which is the same speed as trains operated in the old tunnel.
- The existing monitoring system was designed to monitor and report on construction vibration. It is located too far from the residences, and does not provide the level of detail necessary to isolate and analyze vibration from train operations.
- CSX installed additional monitoring equipment and collected additional data for supplemental monitoring that isolated vibration from train operations.

On July 18, CSX vibration analysts presented summary findings of the supplemental monitoring to DDOT. Data were collected in the vicinity of the CSX townhouse (800 3rd Street SE), the closest dwelling to the new tunnel. Monitors were placed on the tunnel floor, on the ground outside the townhouse, and on the garage floor inside the townhouse. No monitors were placed on the upper floors of the townhouse. Data were collected for 40 hours and captured 25 train pass-by events.

CSX provided two exhibits and a summary table of the supplemental data. This included a graph of broadband vibration over a 10-minute period during a train pass-by (Exhibit 4), a graph isolating train vibration for the same period (Exhibit 5), and a summary table of the 25

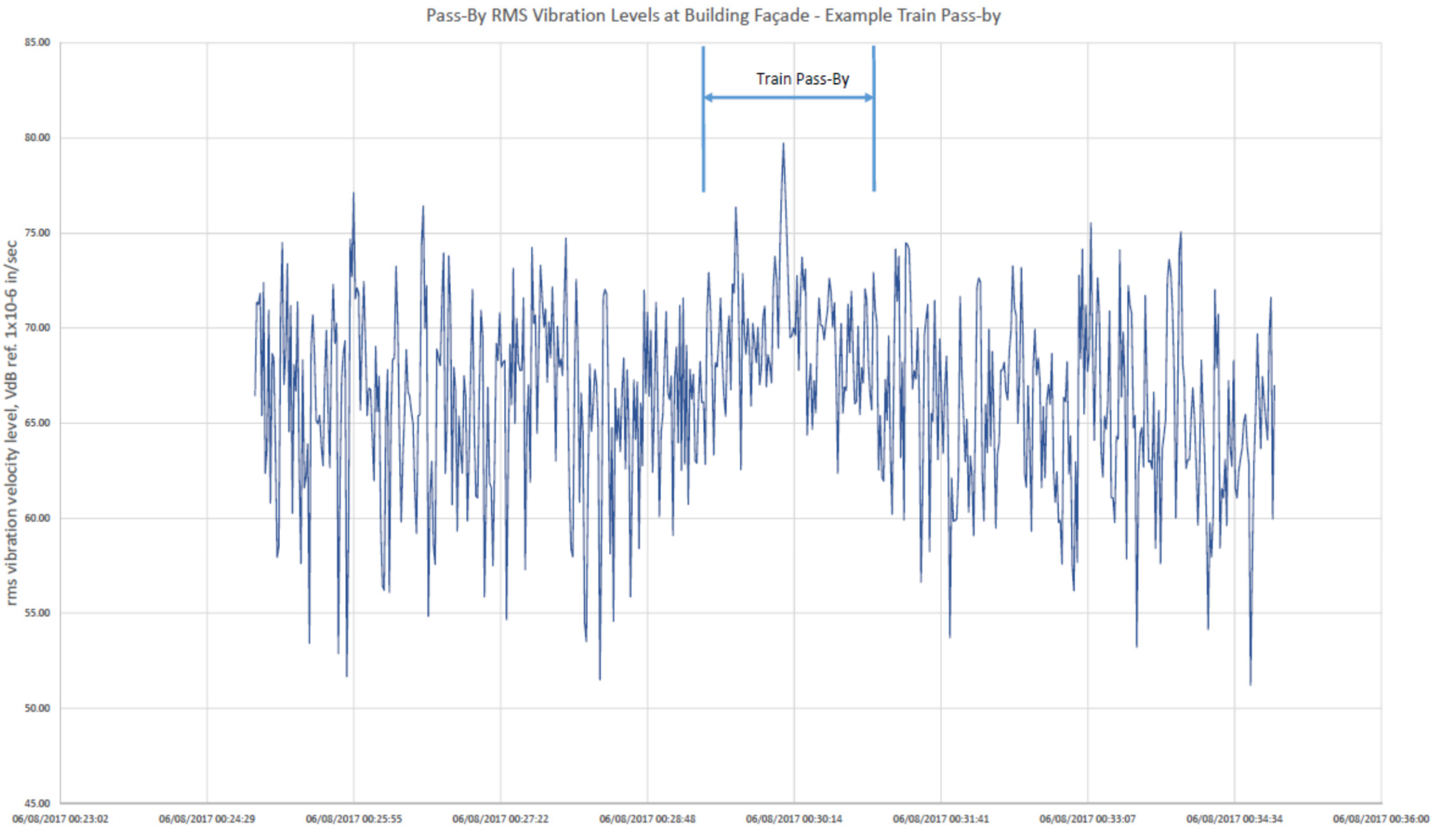

Exhibit 4. Broadband Building Façade Vibration (Event No. 5) – Provided by CSX

pass-bys captured by the supplemental study (Table 1). The graphs showed vibration data associated with Event 5 highlighted in Table 1. DDOT requested a written report of the findings of the supplemental monitoring, but CSX has stated that they will not prepare a formal report.

The graph of broadband vibrations at the building façade (Exhibit 4) indicated that the train vibration was not noticeably higher than background vibration levels. Thus, CSX isolated vibration related to the train pass-by from background vibration by filtering out vibration signals at frequencies not associated with train vibration. Exhibit 5 showed the filtered vibration levels for a single train pass-by at the building façade and at the tunnel slab. The exhibit showed that vibration levels spiked to around 76 VdB, but were typically lower than 70 VdB. Table 1 reports that the average vibration for this event was 68 VdB.

Table 1 summarized each of the recorded pass-bys at the building façade. The reported vibration levels were averaged over the locomotive pass-by and over the rail car pass-by. CSX did not report maximum vibration levels during pass-by events. The FTA Manual is not clear on whether maximum or average values should be reported. Average vibration during the rail car pass-bys ranged from 54 VdB to 68 VdB. Average vibration during the locomotive pass-bys ranged from 59 VdB to 71 VdB. These levels did not exceed the FTA vibration limits of 80 VdB identified in the EIS. The rail car vibration also did not exceed the 75 VdB limit that is appropriate for Occasional Events as described in Section 3. However, several measurements do exceed 65 VdB, and would likely be perceptible by residents.

CSX reported that train speed in the tunnel is currently 25 mph. The tunnel is designed to accommodate speeds up to 40 mph. According to the FTA, vibration varies as 20 times the logarithm of speed (FTA p. 10-9). Thus, a doubling of train speed is expected to lead to an increase in vibration levels of 6 VdB, and an increase of 15 mph (25 mph to 40 mph) would be expected to increase vibration by approximately 4 VdB.

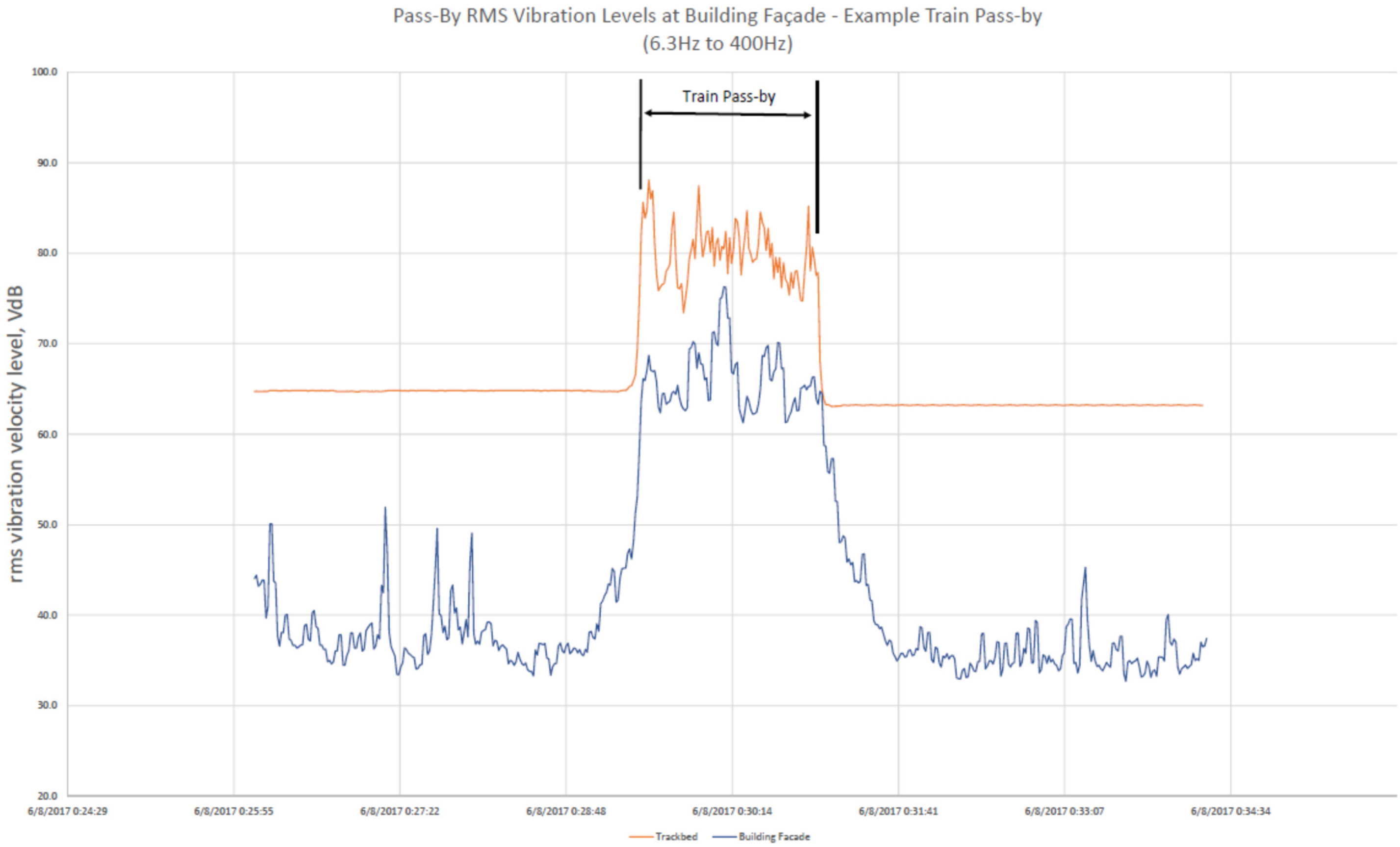

Exhibit 5. Isolated Train Pass-By Vibration – Building Façade Vibration with Tunnel Slab Vibration (Event No. 5) – Provided by CSX

Table 1. Summary of All Train Pass-By Events (Provided by CSX)

Event No.	Date	Pass-By Time	Pass-By Duration (min:sec)	Train Length (ft)	Average RMS Vibration Velocity Levels, VdB (6.3Hz - 400Hz)		
					Locomotive Pass-By	Train Cars Pass-By	Ambient
1	6/7/2017	5:47 PM	05:19	10,991	67	63	44
2	6/7/2017	8:46 PM	01:12	2,102	64	61	43
3	6/7/2017	9:28 PM	02:07	4,132	71	64	43
4	6/8/2017	12:08 AM	01:01	2,246	64	62	40
5	6/8/2017	12:29 AM	01:33	2,943	66	68	39
6	6/8/2017	1:47 AM	03:32	7,475	66	68	37
7	6/8/2017	6:27 AM	01:55	4,209	62	58	44
8	6/8/2017	7:23 AM	04:58	8,097	62	64	46
9	6/8/2017	7:49 AM	04:20	9,486	63	55	48
10	6/8/2017	9:35 AM	07:37	11,026	66	54	48
11	6/8/2017	9:55 AM	02:46	2,379	59	59	48
12	6/8/2017	10:36 AM	03:46	6,589	59	62	49
13	6/8/2017	12:03 PM	04:28	9,387	63	56	47
14	6/8/2017	12:22 PM	03:08	6,592	62	54	48
15	6/8/2017	12:40 PM	03:28	6,356	62	56	48
16	6/8/2017	1:12 PM	04:10	5,936	62	63	50
17	6/8/2017	8:48 PM	01:23	148	63	--	42
18	6/8/2017	11:40 PM	00:50	2,452	64	61	42
19	6/9/2017	1:33 AM	05:54	12,561	63	63	36
20	6/9/2017	2:13 AM	02:42	5,376	64	66	36
21	6/9/2017	2:38 AM	02:22	4,775	59	57	37
22	6/9/2017	3:09 AM	02:41	5,394	65	64	38
23	6/9/2017	3:52 AM	03:07	6,610	62	56	38
24	6/9/2017	7:50 AM	04:52	10,212	65	55	48
25	6/9/2017	9:34 AM	01:49	3,598	64	65	49

5. CSX Construction Monitoring Program

As part of the mitigation agreed to in the EIS, CSX established a construction vibration monitoring program for the project. They installed eight monitoring stations along the construction site, including Location No. V3, in the courtyard at the front-row residents in the 300 block. The monitoring station locations are shown in Exhibit 6, and a photo of Location No. V3 is shown in Exhibit 7. The monitors were installed in April 2015, before construction began, and have been operating continuously since. CSX provides monthly reports that summarize the measurements at each location and identify exceedances of the established vibration criteria.

The construction monitoring system is not set up to provide useful data to assess human annoyance vibration impacts due to train operations. The monitors are located too far from residences, and the data collection methodology does not allow train vibration to be isolated. This data is used by CSX to monitor and adjust construction activities to stay below the threshold to minimize or avoid potential structural damage to buildings.

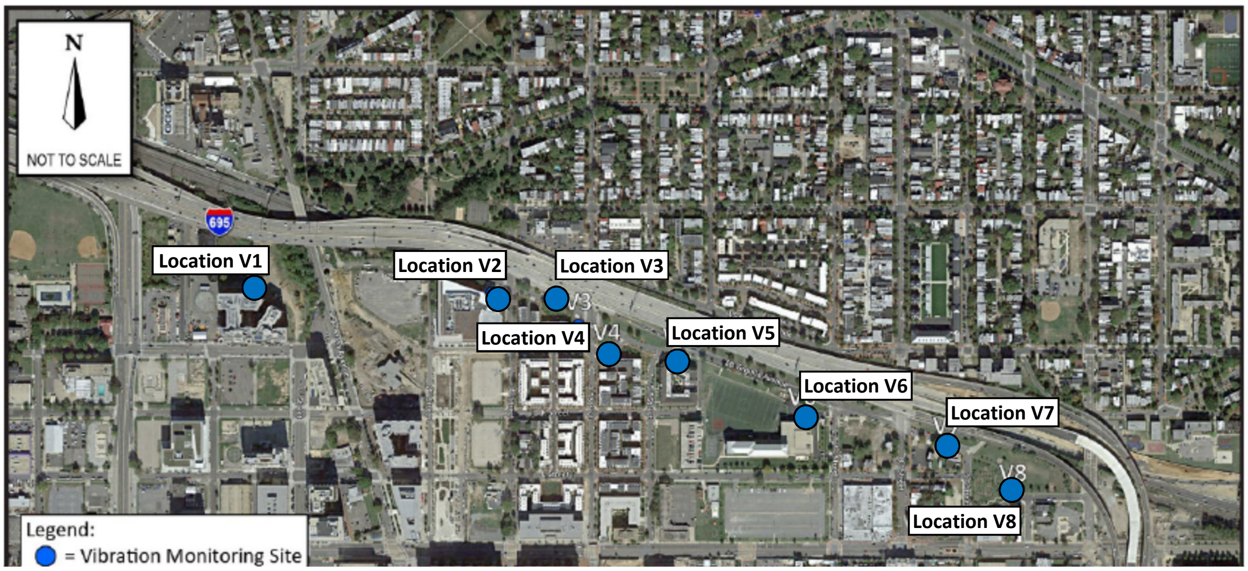

Exhibit 6. Construction Vibration Monitoring Locations

Exhibit 7. Monitoring Location No. 3 in 300 Block of Virginia Avenue

6. Key Takeaways

Key takeaways from this review of the CSX vibration monitoring program are summarized below:

1. Based on the resident complaints and reports (Section 3.1), the experience of the DDOT observers (Section 3.2), and the reported supplemental operations monitoring results from CSX (Section 4), *it is probable that train operations have caused vibrations that exceed perceptible vibration levels* (65 VdB). The data reported by CSX in Table 1 showed vibration levels above the perceptible vibration limit of 65 VdB when trains were confirmed to be operating in the tunnel.
2. The construction vibration monitoring system was installed as a mitigation measure required by the EIS (Section 5.7.4) is set up to monitor and adjust construction activities to minimize the risk of structural damage to buildings. It is not set up to provide useful data to assess human annoyance vibration impacts due to train operations. Therefore, supplemental monitoring measurements were collected to assess potential human annoyance caused by train operations.
3. While the average values for vibration levels reported by CSX for the supplemental monitoring measurements are in the range of perceptible limits, they do not exceed the limits identified in the EIS (80 VdB) for human annoyance for infrequent events. The average values also do not exceed the lower thresholds that would be appropriate for rail car vibrations and future increases to more than 30 trains per day (75 VdB).
4. CSX conducted a vibration baseline analysis for the purpose of construction monitoring only. There was no baseline vibration analysis for train operations conducted before trains began running in the Phase 1 tunnel. Therefore, it is not clear if, or how much, vibration has increased since trains began operating in the new tunnel. It is also not clear if, or how much, the mitigation measures installed by CSX reduced the vibration. Since there is no baseline data to compare, the resident complaints serve as the only meaningful measure of relative increase in vibration.
5. CSX did not provide a formal supplemental monitoring report and left a number of questions raised by DDOT and the community unanswered, such as:
    a. Were trains operating in the VAT during the times that residents reported experiencing vibration?
    b. Are vibration levels higher on upper floors of residences?
    c. Why do residents one to two blocks away from the tunnel report experiencing vibration?
    d. Were the weight, length and speed of trains operating during the supplemental monitoring typical of the trains that operate in the Virginia Avenue Tunnel? Did the measurements collected constitute a statistically significant sample?
    e. What are the expected vibration levels when CSX begins operating trains simultaneously in both tunnels and operating speeds are increased to the design speed of 40 mph?
    f. What are the other sources of vibration in the area? In particular, what non-train sources resulted in measured vibration levels during periods of no train activity that were similar to those measured during a train pass-by?

7. Recommendations and Next Steps

To demonstrate transparency and address immediate concerns, we recommend that CSX take the following actions:

1. Provide a formal report prepared by the independent vibration monitoring consultant outlining the methodology, justification, and conclusions of the supplemental monitoring. Refer to Attachment 5 regarding letter to CSX from FHWA.
2. Include maximum vibration levels for both locomotive pass-by and rail car pass-by in the data summary (Table 1) in addition to the average levels currently reported.
3. Confirm whether a train was present or not during the times residents reported perceptible vibrations. A partial list of times is included in Attachment 4.
4. Provide the raw data collected in the supplemental monitoring.

To adequately address ongoing concerns from residents related to vibrations from rail operations in the Virginia Avenue Tunnel, additional analysis of key data is needed. This analysis should include additional data collection, provide a discussion on the appropriate human annoyance criteria, and include a discussion of the impacts of an increase in train operating speed. Elements of the independent analysis should include:

1. Conduct a follow-up data collection program to include the following elements:
   a. Collect vibration measurements at the CSX townhouse, one front row residence and one additional residence that is more than one block away from the tunnel
   b. Collect vibration measurements on the ground floor and top floor at each location
   c. Report train pass-by information for the monitoring period to include time of pass-by, train length, train weight, and train speed.
   d. Collect data over a period of time sufficient to provide a statistically significant sample size that includes the appropriate range of typical train lengths and weights.
2. Provide an estimate, based on the follow-up data collection results, of vibration levels with a train in each tunnel traveling at 40 mph. This will provide a basis for comparison to the analysis completed in the EIS.
3. As requested by FHWA in their May 10, 2017 letter (Attachment 5), CSX should reduce operating speed in the tunnel until the results of the follow-up analysis are provided.

Attachments

1. Vibration Monitoring Report (rev. March 2014)
2. CM Allen letter to DDOT (May 10, 2017)
3. DDOT response letter to CM Allen (May 23, 2017)
4. Email comments from Meredith Fascett with responses (May 12, 2017)
5. FHWA letter to CSX (May 10, 2017)
6. CSX response letter to FHWA (June 6, 2017)
7. Amec/Foster Wheeler letter to FHWA (September 19, 2017)

Attachment 1

Vibration Monitoring Report

VIRGINIA AVENUE TUNNEL RECONSTRUCTION PROJECT

Revised March 2014

VIBRATION ANALYSIS REPORT

VIRGINIA AVENUE TUNNEL
RECONSTRUCTION PROJECT
WASHINGTON, DC

VIBRATION ANALYSIS REPORT

REVISED: March 2014

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

AAR	Association of American Railroads
CSX	CSX Transportation, Inc.
DDOT	District of Columbia Department of Transportation
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HVAC	Heating, Ventilation, and Air Conditioning
NEPA	National Environmental Policy Act
PPV	Peak Particle Velocity
RMS	Root Means Square
USDOT	United States Department of Transportation
VAT	Virginia Avenue Tunnel
VdB	Vibration decibel

STANDARDS

The following guidelines were utilized for the vibration impact and mitigation assessment:

Federal Transit Administration, May 2006. *Transit Noise and Vibration Impact Assessment*, Technical Manual FTA-VA-90-1003-06.

ES EXECUTIVE SUMMARY

This study was conducted to assess potential vibration impacts during and after the proposed reconstruction of the Virginia Avenue Tunnel (VAT), which is located in the Capitol Hill neighborhood of the District of Columbia. Built over 100 years ago, the 3,800 foot long tunnel is located beneath eastbound Virginia Avenue SE from 2nd Street SE to 9th Street SE; beneath Virginia Avenue Park between 9th and 11th Streets SE; as well as the 11th Street Bridge right-of-way. The tunnel is also aligned along the south side of Interstate 695. The tunnel portals are located a short distance west of 2nd Street SE and a short distance east of 11th Street SE. CSX Transportation proposes to replace the existing single-track tunnel with a newly constructed two-track configuration that provides the necessary vertical clearance (minimum 21 feet) to allow for double-stack intermodal container freight train operations.

STUDY OVERVIEW AND SCOPE

This study was conducted in accordance with the procedures outlined in the Federal Transit Administration's *Transit Noise and Vibration Impact Assessment* guidelines (FTA 2006). Utilizing the FTA guidelines and applicable criteria, vibration impacts were evaluated for human annoyance, impact to special buildings, and building damage as applicable to each of the project alternatives during construction and subsequent freight operations. The Federal Railroad Administration (FRA) also uses the same guidelines for evaluating train vibration impacts. The scope of the study is summarized in **Table ES-1**.

Table ES-1. Vibration Study Scope

	ALTERNATIVES			
TOPIC EVALUATED	ALTERNATIVE 1 – EXISTING / NO BUILD	ALTERNATIVE 2 – REBUILT TUNNEL / TEMPORARY RUNAROUND TRACK	ALTERNATIVE 3 – TWO NEW TUNNELS	ALTERNATIVE 4 – NEW PARTITIONED TUNNEL / ONLINE REBUILD
Human Annoyance from Construction	Not applicable	Evaluated	Evaluated	Evaluated
Impact to Special Buildings from Construction	Not applicable	Evaluated	Evaluated	Evaluated
Building Damage from Construction	Not applicable	Evaluated	Evaluated	Evaluated
Human Annoyance from Train Operations	Evaluated	Evaluated	Evaluated	Evaluated
Impact to Special Buildings from Train Operations	Evaluated	Evaluated	Evaluated	Evaluated
Building Damage from Train Operations	Evaluated	Evaluated	Evaluated	Evaluated

"Special Buildings" is an FTA designation for buildings that can be sensitive to vibration. The band practice area at the US Marine Corps facility (Room G62 in Building 25) was evaluated using the FTA "Special Building" criteria as part of this study.

STUDY METHODOLOGY: CONSTRUCTION

Vibration during the construction of this project would result primarily from the utilization of specialty construction equipment in the performance of major construction activities such as removal of the existing surface roadway and underground tunnel elements, installation of support of excavation measures, excavation and backfill for the proposed tunnel reconstruction, as well as restoration of the Virginia Avenue roadway and streetscape. Vibration levels produced by construction equipment were obtained from the FTA *Transit Noise and Vibration Impact Assessment* (FTA 2006). Based on the typical vibration levels for the various pieces of construction equipment anticipated to be used, calculations were performed to determine the distances at which potential vibration impacts could occur during the various construction activities. Distances from the construction activity to nearby buildings were calculated based on the proposed location of each build alternative and the specific construction functions that would need to be performed for that alternative.

The results of these calculations were compared to the FTA Criteria for Human Annoyance, Special Buildings, and Building Damage. For this study a conservative approach was utilized by applying the FTA limit specified for "fragile buildings" to all buildings, regardless of the type and age.

STUDY METHODOLOGY: TRAIN OPERATIONS

Existing background and train pass-by vibration levels were measured at 12 sites along the Virginia Avenue Tunnel. Results of these vibration measurements provided data that were used to:

- Determine vibration levels generated by train pass-bys. The highest recorded train vibration level was used as the train vibration source in calculating the impact distances in order to avoid understating future vibration levels.
- Calculate the degree to which the existing tunnel structure reduces vibrations from train pass-bys.
- Calculate the vibration transferability characteristics of the soil.

The measured data was used to depict vibration levels from current train operations at nearby buildings under Alternative 1 (Existing /No Build). Furthermore, this data then served as the basis to predict the potential impacts from train operations for Build Alternatives 2, 3, and 4. The following issues were addressed in this process:

- The centerline of the southernmost track in the proposed tunnel locations for each of the three candidate build alternatives was utilized to determine the distance between the vibration sensitive receptors (buildings and people) and the vibration sources (construction and train operations).

- The shallowest tunnel depth adjacent to the sensitive receptors was used for calculating the highest possible vibration levels which would be produced from train operations.
- The proposed maximum operating train speed for the new tunnels of 40 mph was used. This is the most conservative approach which would predict higher vibration levels.
- The proposed track configuration for each of the build alternatives was used, including the elimination of the existing "turnout", (a transfer point between two tracks) near the east tunnel portal where the single track in the tunnel transitions to a two track configuration.
- Vibration impact predictions assumed two trains were traveling in the tunnel simultaneously.
- Train weight was evaluated and was not modified for assessing vibration impacts during future operations. Locomotives are the heaviest component of a freight train. Changes in locomotive weight or the number of locomotives utilized per train are not anticipated. Replacing the tunnel will introduce double-stacked intermodal container operations to this segment of the rail network. However, historical data for the rail industry clearly indicates that intermodal containers are one of the lightest classes of freight shipped by rail. Trains that are primarily or entirely comprised of double-stacked intermodal containers weigh less than many current trains currently utilizing the Virginia Avenue Tunnel (see Chapter 2 for additional information).
- Reconstruction of the tunnel under any of the candidate build alternatives would include replacing the existing dirt track bed with a 3-foot thick concrete slab. A large mass such as a 3-foot thick reinforced concrete slab will reduce the vibration energy generated by train operations. **However, this potential reduction in vibration provided by the reinforced concrete floor was <u>not</u> considered** when modeling future vibration levels from train operations under any of the build alternatives. This is a very conservative approach and would predict higher vibration levels than are anticipated with the modern track bed that will be used.

STUDY FINDINGS: GENERAL

- The soil vibration transferability characteristics along the entire length of the tunnel are consistent and predictable at varying distances from the tunnel. This, in combination with the observed geologic features of the area, supports the finding that the calculated vibration transferability characteristics of the soils at the specific data collection sites are applicable along the entire length of the tunnel.
- The degree to which the existing tunnel structure reduces vibration transmission into the surrounding soils from train operations is consistent and likewise predictable along the entire length of the tunnel. This supports the finding that the calculated vibration reductions from the proposed tunnel structure for each build alternative are applicable along the entire length of the tunnel.
- Vibration measurements conducted in May 2012 and December 2013 did not reveal any major differences between tunnel reduction effect and soil transferability characteristics.

- Numerous vibration events were recorded when there were no train operations in the tunnel. Many of these events produced vibration levels that were of equal or greater magnitude than vibration levels generated from train operations. It was beyond the scope of this study to determine the specific nature of the events causing these vibrations. However, neither the frequency nor the magnitudes of these "non-train" vibrations are unusual in an urban environment.
- There was one observed instance in the December 2013 data where a high vibration incident unrelated to train operations occurred during a train passage. This was determined to be a concurrent event by analyzing the vibrations from that same train at other locations along the tunnel. In addition there were numerous additional vibration events not related to train passage that were recorded that were equal or greater than those recorded during train passage.

Specific impacts of the vibration study are summarized in **Table ES-2** and are discussed in further detail in the following sections.

Table ES-2. Vibration Study Results

TOPIC EVALUATED	ALTERNATIVES			
	ALTERNATIVE 1 – EXISTING/ NO BUILD	ALTERNATIVE 2 – REBUILT TUNNEL / TEMPORARY RUNAROUND TRACK	ALTERNATIVE 3 – TWO NEW TUNNELS	ALTERNATIVE 4 – NEW PARTITIONED TUNNEL / ONLINE REBUILD
Human Annoyance from Construction	Not applicable	Potential Impact - Mitigation Required	Potential Impact - Mitigation Required	Potential Impact - Mitigation Required
Impact to Special Buildings from Construction	Not applicable	None Predicted	None Predicted	None Predicted
Building Damage from Construction	Not applicable	None Predicted	None Predicted	None Predicted
Human Annoyance from Train Operations	None Detected	None Predicted	None Predicted	None Predicted
Impact to Special Buildings from Train Operations	None Detected	None Predicted	None Predicted	None Predicted
Building Damage from Train Operations	None Detected	None Predicted	None Predicted	None Predicted

STUDY FINDINGS: CONSTRUCTION

- **Human Annoyance:** There will be the potential for human annoyance impacts during certain construction operations for each of the build alternatives. Mitigation measures would be considered if construction activities or equipment were to operate close to residential or institutional buildings and potentially cause human annoyance. In addition, contractors may need to use different types of equipment for each activity versus those used for predicting vibration in this study; therefore, a plan will be put in place where vibration levels will be monitored during construction. If measurement results show that vibration levels exceed impact thresholds, construction methods will be reevaluated to bring vibrations back under the thresholds where possible or mitigations will be implemented. (Further information on potential vibration mitigations can be found in Chapter 6 of this report.)

- **Special Buildings:** The Marine Band Practice Hall is considered as an auditorium under the special building category of FTA guidelines. Results of the existing vibration measurements indicated that some of the building internal sources, such as HVAC system are a prevalent source of vibration. Construction or operation vibration impacts are not predicted in the Practice Hall.
- **Building Damage:** There would be no vibration related building damages due to construction operations under any of the build alternatives.

STUDY FINDINGS: TRAIN OPERATIONS

- **Human Annoyance**: Results of vibration measurements and modeling indicate that there is "No Impact" to human annoyance per FTA guidelines from train operations under any of the Build Alternative tunnel configurations. Measurements and modeling show that train operation vibrations would cause human annoyance at distances ranging from 12 to 30 feet from the center of the track depending on the alternative. See **Table ES-3** for additional details.

Table ES-3. Vibration Impact Distances from Train Operations (Centerline of Tracks) in the Tunnel

ALTERNATIVES	DISTANCE TO POTENTIAL VIBRATION HUMAN ANNOYANCE (FEET)
Existing/No Build	12
Alternative 2 (open trench during construction)	12
Alternative 2	30
Alternative 3	30
Alternative 4	30

While Alternatives 2, 3, and 4 have equal vibration impact distances the proposed tunnel alignments vary by alternative. Between 2nd and 9th Streets Alternative 3 would be aligned closest to the sensitive receptors and the centerline of the southernmost track would be approximately 15 feet south of the exterior face of the existing tunnel's south wall. However, even in this area, the nearest buildings are at least 12 feet further away from the outside limit for human annoyance (i.e., 42 feet from the proposed track centerline). Therefore, the conclusion of "None Predicted" is an appropriate finding for the potential of future train operations to exceed the human annoyance threshold for any of the candidate build alternatives in accordance with FTA guidelines. As indicated in Table ES-3, human annoyance impacts would not occur at distances greater than 30 feet away from the track centerline even if there were two trains traveling through the tunnel or tunnels at the same time. Accordingly, vibration impacts are not anticipated to result from future, post-construction train operations because the nearest residential building to any of the candidate build alternative alignments is located at least 42 feet from the southernmost proposed track centerline.

- **Impact to Special Buildings**: Results of the analysis indicates that there would be no impacts at the Marine Band Practice Hall (Room G62 in Building 25) per the FTA guidelines for an auditorium.
- **Building Damage**: The analysis indicates that under all of the candidate build alternatives, nearby building structures are not expected to be impacted**.** The calculated

impact distance (27 feet from track centerline) for potential building damage vibration is less than the minimum depth from the ground surface to the bottom of the tunnel of 34 feet. Furthermore, the shortest possible path between the vibration source (track center line) and a building structure is 52 feet. Therefore, any building at ground level, even a hypothetical structure located directly above the tunnel, would not be damaged by train operations. (See Figure 5-1 and Table 5-6 in Chapter 5 of this report for further details).

1 INTRODUCTION

1.1 PURPOSE OF VIBRATION STUDY

The purpose of this study is to evaluate existing and assess future vibration levels at sensitive locations along the Virginia Avenue Tunnel (VAT) Reconstruction Project. This report was updated in order to reflect comments and input received from the Federal Highway Administration (FHWA), District Department of Transportation (DDOT), other governmental agencies and the public. Additional vibration tests were conducted in December 2013 to characterize the existing vibration levels at several of the buildings closest to the proposed project during a typical 24 hour period and results were used to further refine the predicted vibration affects from the proposed project.

The study results are described in six sections. Chapter 1 presents the Virginia Avenue Tunnel project description. Chapter 2 explains general vibration terminology. Chapter 3 presents the guidelines and criteria used to assess the potential vibration impacts. Chapter 4 presents the results of baseline vibration measurements. Chapter 5 analyzes the potential impacts of construction and future train operations through the tunnel. Chapter 6 discusses possible mitigation measures that could be implemented to reduce potential vibration impacts of the proposed project.

1.2 PROJECT DESCRIPTION

CSX Transportation, Inc. (CSX) is proposing to reconstruct the Virginia Avenue Tunnel. The tunnel is located in the Capitol Hill neighborhood of the District of Columbia, as shown in **Figure 1-1**. The existing tunnel is 3,800 feet in length and aligned along the south side of Interstate 695 (I-695), located beneath eastbound Virginia Avenue SE from 2nd Street SE to 9th Street SE; Virginia Avenue Park between 9th and 11th Streets SE; and the 11th Street Bridge right-of-way. The tunnel portals are located a short distance west of 2nd Street SE and a short distance east of 11th Street SE. The tunnel is an integral part of CSX's freight rail network that encompasses approximately 21,000 miles of railroad track in the District, 23 states, and the Canadian provinces of Ontario and Quebec. Specifically, the tunnel is located along CSX's eastern seaboard freight rail corridor, which stretches from the southeast through the Mid-Atlantic and connecting to the Midwest, thereby making it a key link in the nation's network of major freight rail lines.

If the Virginia Avenue Tunnel were not replaced or reconstructed, it will continue to require increasingly higher levels of investment for maintenance and repair, resulting in more frequent service interruptions and higher risks for localized disturbances. In addition, the tunnel has notable operational deficiencies. Specifically, the tunnel has just a single railroad track, which limits the flow of freight train traffic. Virginia Avenue Tunnel was identified as a bottleneck on the east coast (District of Columbia Freight Forum, Volume 1, Issue 1 [January 2012]). Furthermore, the tunnel does not have sufficient vertical clearance to accommodate rail cars that are loaded with two intermodal containers set one on top of the other, which is called "double-stacking". The VAT Reconstruction Project will transform the tunnel to a two-track configuration and provide the necessary vertical clearance to allow double-stack intermodal container freight train operations. Reconstruction of the tunnel will allow more efficient freight movement (Freight Forum, January 2012). In order to accommodate double-stack intermodal container freight trains, track lowering will be required at the New Jersey Avenue SE Overpass to provide the 21-foot minimum clearance as well as in the reconstructed tunnel.

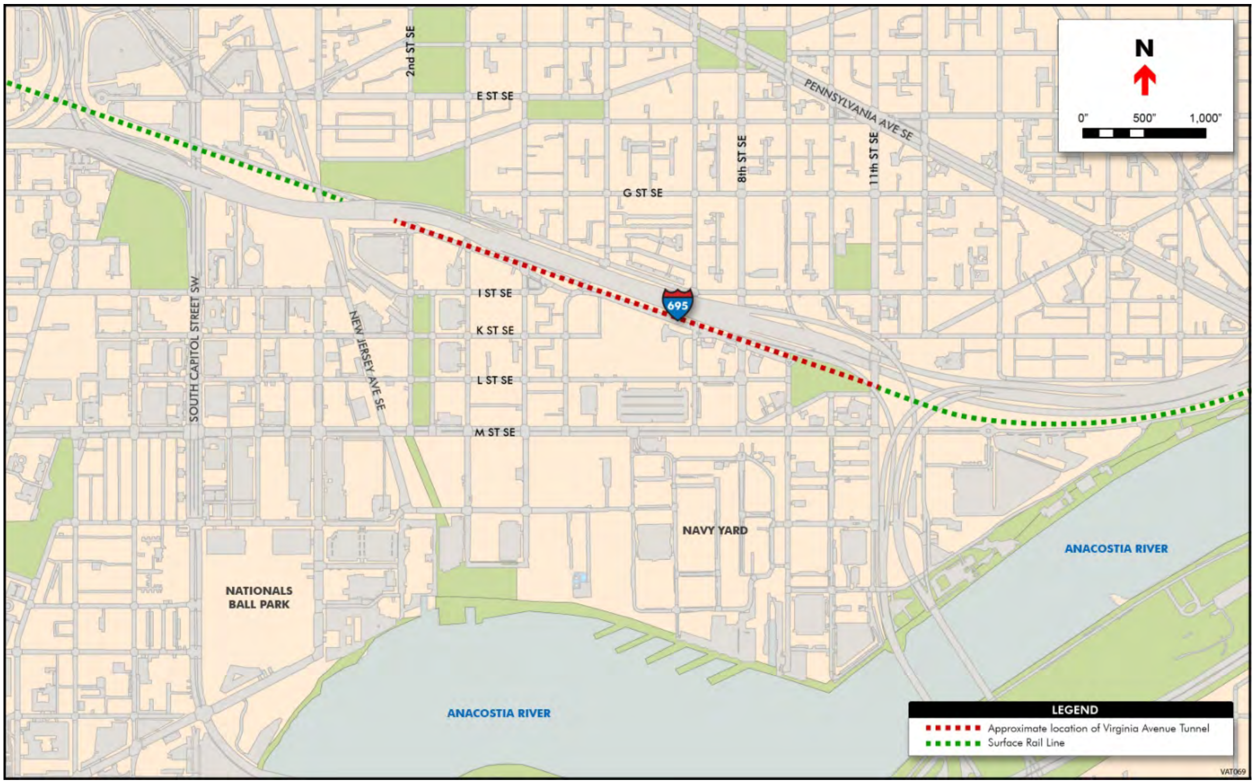


Figure 1-1. Project Location Map

The following alternatives are being considered for the project:

Alternative 1 – No Build: The tunnel would not be rebuilt under this alternative. However, the railroad would continue to operate trains through the tunnel and at some point, emergency or unplanned major repairs or rehabilitation could be required to this critical, aging infrastructure that might prove disruptive to the community. See **Figure 1-2** at the end of this chapter.

Alternative 2 – Rebuilt Tunnel / Temporary Runaround Track: This alternative involves rebuilding the existing Virginia Avenue Tunnel. It would be rebuilt with two railroad tracks and adequate vertical clearance to accommodate double-stack intermodal container freight trains. It would be rebuilt in generally the same location, except the centerline of the rebuilt two-track tunnel would be aligned approximately seven feet to the south of the existing tunnel center line. It would be rebuilt using protected open trench construction methods. During construction, freight trains would be temporarily routed through a protected open trench outside the existing tunnel (runaround track). The runaround track would be aligned to the south and generally parallel to the existing tunnel, and would be located below street level. Due to new columns associated with the rebuilt 11th Street Bridge, the runaround track would slightly separate from the tunnel alignment on the east end starting just west of Virginia Avenue Park. Safety measures such as securing fencing would be used to prevent pedestrians and cyclists from accessing the runaround track. See **Figure 1-3** at the end of this chapter.

Alternative 3 – Two New Tunnels: This alternative involves replacing the existing Virginia Avenue Tunnel with two new permanent tunnels constructed sequentially. Each new tunnel would have a single railroad track with enough vertical clearance to allow double-stack intermodal container freight trains. A new parallel south side tunnel would be built first as trains continue operating in the existing Virginia Avenue Tunnel. This tunnel would be built using protected open trench construction methods. After the south side tunnel is completed, train operations would switch over to the new tunnel and the existing Virginia Avenue Tunnel would be demolished and rebuilt. With the exception of operating in a protected open trench for approximately 230 feet immediately east of the 2nd Street SE portal (within the Virginia Avenue SE segment between 2nd and 3rd Streets SE), trains would operate in enclosed tunnels throughout construction under Alternative 3. Throughout most of the length of the rebuilt tunnel, the two tunnels would be separated by a center wall. This center wall would be the new centerline of the two tunnels, and it would be aligned approximately 25 feet south of the existing tunnel centerline, between 2nd and 9th Streets SE. Due to new columns associated with the rebuilt 11th Street Bridge, the tunnels would be separated on the east end starting just west of Virginia Avenue Park, resulting in two separate single-track tunnels and openings at the east portal. See **Figure 1-4** at the end of this chapter.

Alternative 4 – New Partitioned Tunnel / Online Rebuild: Alternative 4 would result in a new tunnel with two permanent tracks. Similar to Alternative 3, the new tunnel would be partitioned and have enough vertical clearance to allow double-stack intermodal container freight trains. It would be aligned approximately 17 feet south of the existing tunnel's centerline. The new tunnel would be built using protected open trench construction methods. The rebuild would occur 'online', meaning that during the period of construction, the protected open trench would accommodate both construction activities and train operations. Maintaining safe and reliable temporary train operations is a more complicated endeavor under Alternative 4 than under the other two Build Alternatives because of the online rebuild approach. See **Figure 1-5** at the end of this chapter.

Under all candidate build alternatives, the total length of the rebuilt Virginia Avenue Tunnel will be extended by approximately 330 feet on the east end. The new east tunnel portal will be located northeast of the existing M Street SE / 12th Street SE T-intersection.

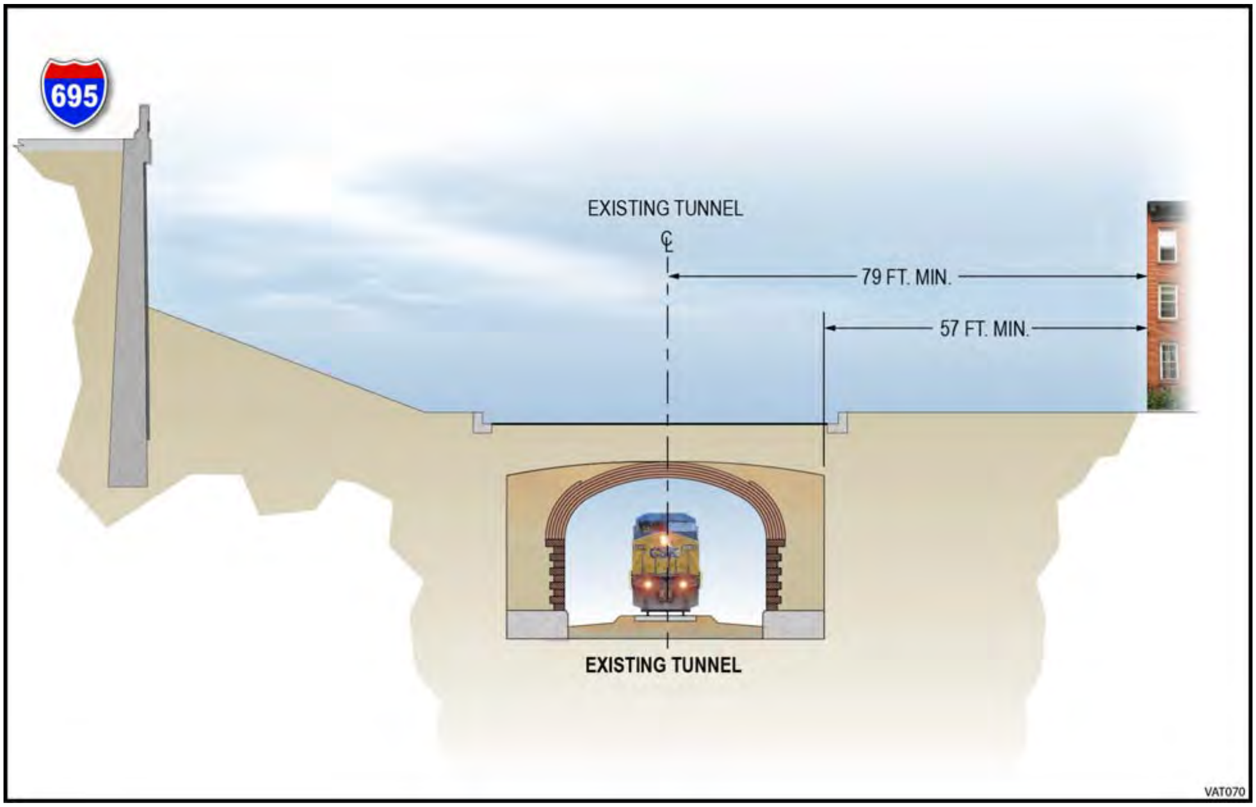


Figure 1-2. Alternative 1 – No-Build

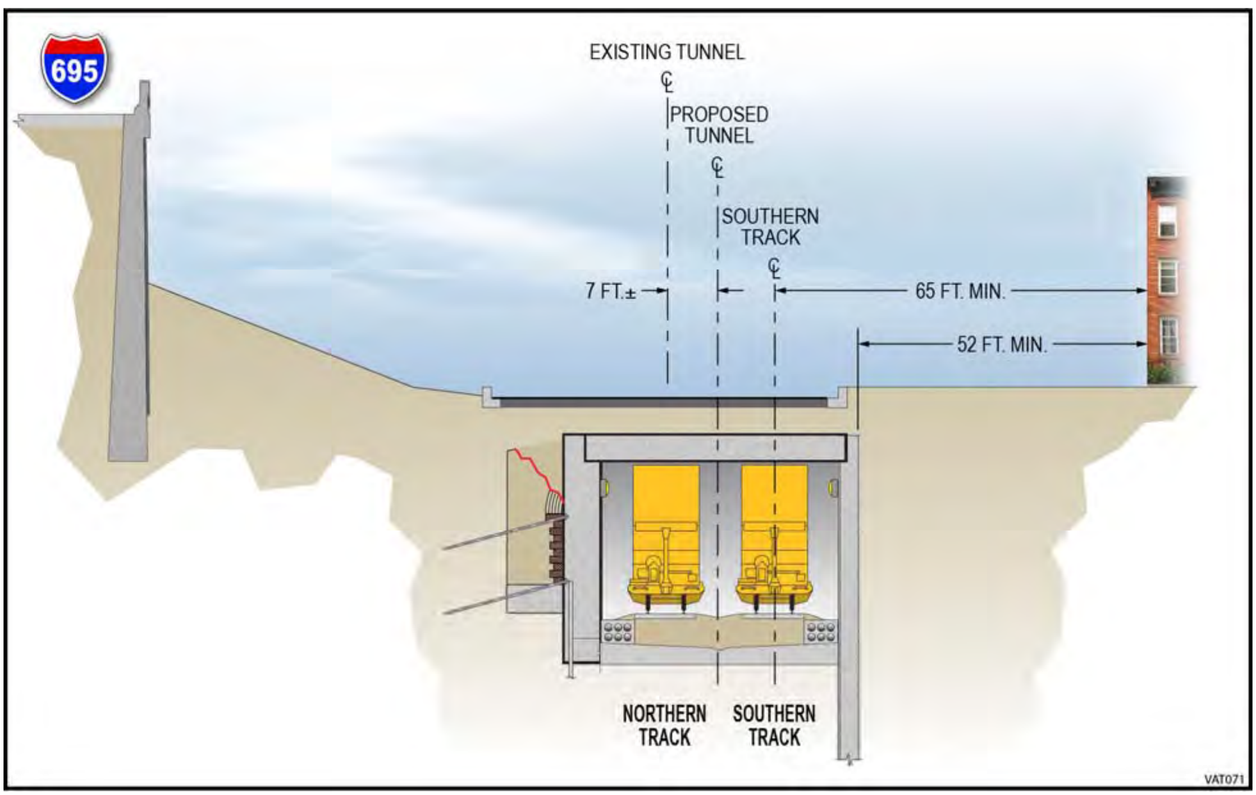


Figure 1-3. Alternative 2 – Rebuilt Tunnel / Temporary Runaround Track

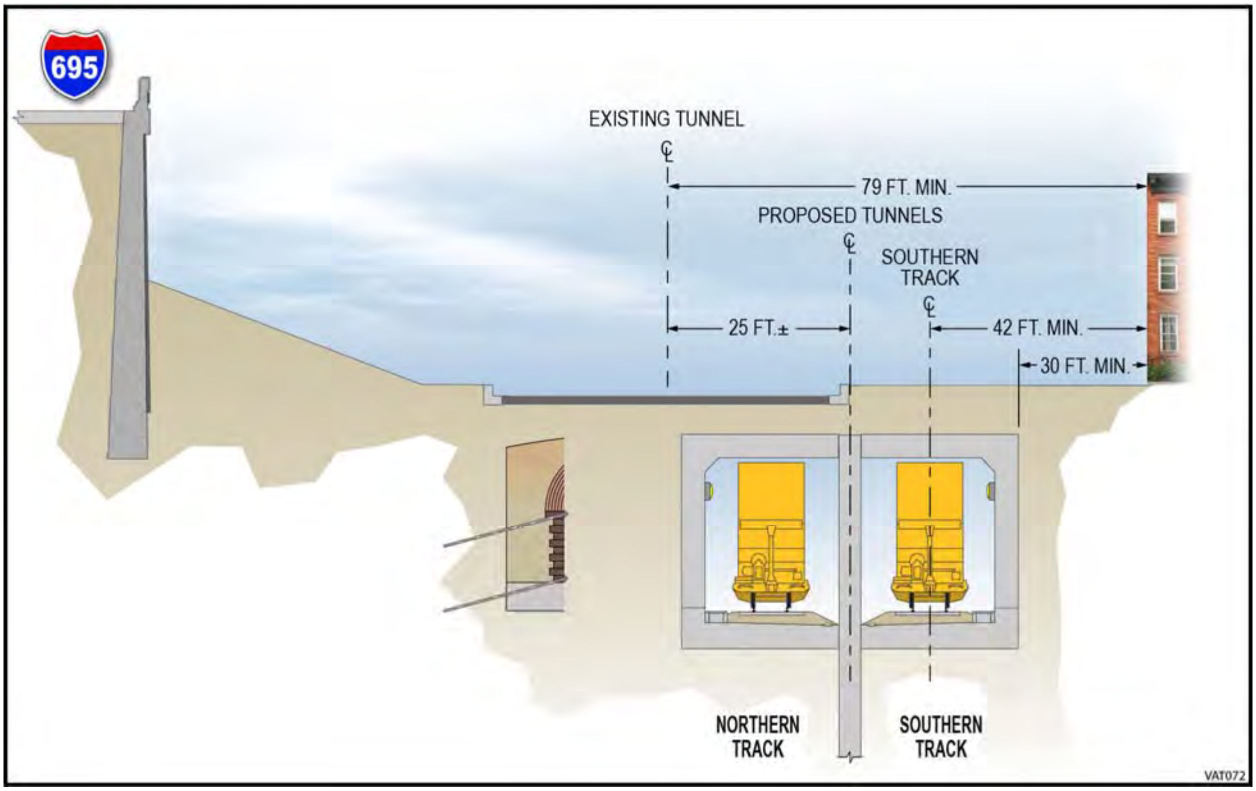


Figure 1-4. Alternative 3 – Two New Tunnels

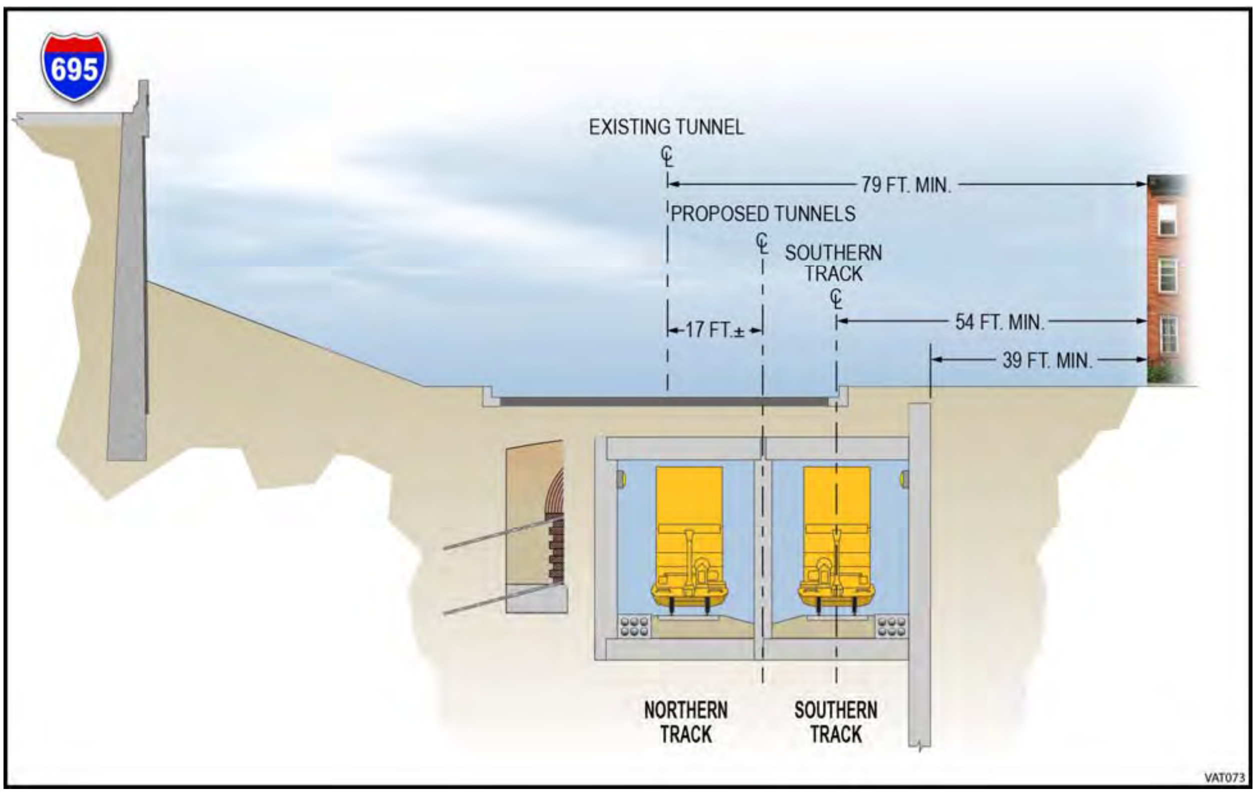


Figure 1-5. Alternative 4 – New Partitioned Tunnel / Online Rebuild

2 VIBRATION BACKGROUND

This section describes the basic concepts and general terminology of vibration and provides background for the assessment procedures described in the later sections.

Vibration is an oscillatory motion that can be described in terms of displacement, velocity, or acceleration. Displacement, in the case of a vibrating floor, is simply the distance that a point on the floor moves away from its static position. The velocity represents the instantaneous speed of the floor movement, and acceleration is the rate of change of the speed. The response of humans, buildings, and equipment to vibration is normally described using velocity or acceleration. In this report, velocity will be used to describe ground-borne vibration.

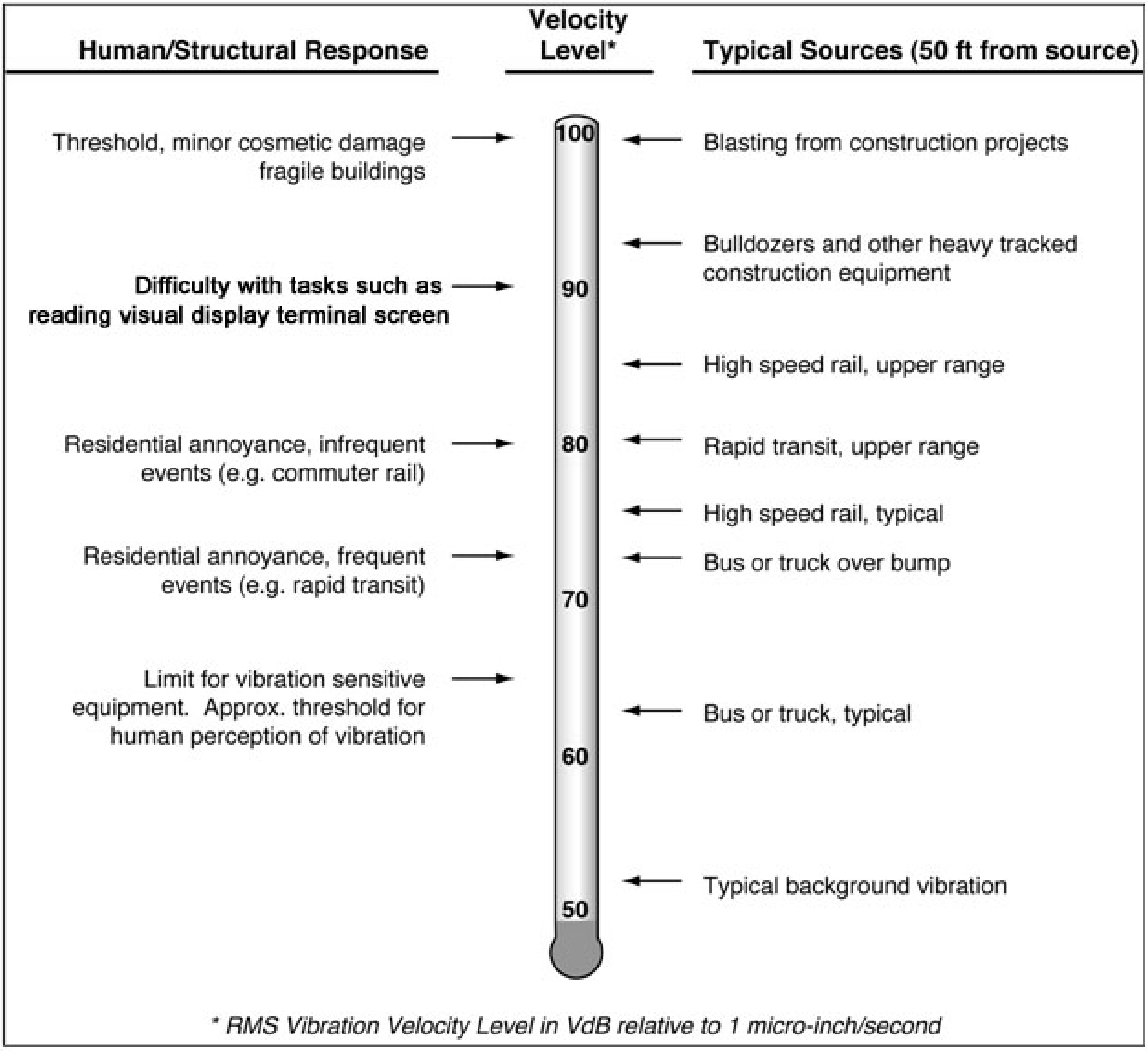
Vibration amplitudes are usually expressed as either peak particle velocity (PPV) or the root mean square (RMS) velocity. The PPV is defined as the maximum instantaneous peak of the vibration signal in inches per second. The RMS of a signal is the average of the squared amplitude of the signal in inches per second. Although PPV is appropriate for evaluating the potential of building damage, it is not suitable for evaluating human response. Since it takes some time for the human body to respond to vibration signals, RMS amplitude is more appropriate to evaluate human response to vibration than PPV.

The Federal Transit Administration (FTA), a division of the U.S. Department of Transportation (USDOT), uses the abbreviation "VdB" for vibration decibels (FTA, 2006) to reduce the potential for confusion with sound decibel. When determining the VdB level for vibration sources such as trains, first a conversion factor of 4 is applied to the measured PPV value to obtain the RMS value. This conversion number is known as the crest factor and is the ratio between the PPV amplitude and the RMS amplitude. Next, the RMS vibration value is logarithmically adjusted against the reference value of 1 micro-inch per second and multiplied by 20 to be expressed in VdB values used throughout this report and shown as the following equation:

$$VdB = 20 \ x \ Log10(\frac{v}{vref})$$

Where: v = PPV/4 and $vref$ = 1× 10-6 in/sec

Figure 2-1 illustrates common vibration sources and the corresponding human and structural response to the associated ground-borne vibration. As shown in the figure, the threshold of perception for human response is approximately 65 VdB; however, human response to vibration is not usually significant unless the vibration exceeds 70 VdB.



Source: FTA, 2006

Figure 2-1. Typical Levels of Ground-Borne Vibration

VIBRATION FROM TRAINS

Vibration from trains is caused by interaction of the wheels rolling on the tracks when moving. The force caused by this interaction depends on train speed, the smoothness of the rails and wheels, and the resonance frequencies of the vehicle suspension and track support systems. When vibration does occur, it is then radiated into the surrounding ground. The extent to which the vibration waves propagate away from the track depends upon factors such as the strength of the original wave, the depth to bedrock, and the soil type. However, the amplitude of the wave is typically diminished with distance. This diminishment of energy results from both the material dampening of the wave created by the medium and the expansion of the wave front. If the vibration reaches building foundation, it can cause floor, walls, and ceiling in living spaces to vibrate.

VIBRATION FROM CONSTRUCTION

An additional source of vibration would be related to the construction of the proposed Virginia Avenue Tunnel. The operation of construction equipment causes ground vibrations that spread through the surrounding ground. While these vibrations tend to diminish over distance, depending upon the type of construction equipment and duration of the activity, nearby sensitive receptors could be affected. Human annoyance from construction is typically dependent upon the extent, distance, and duration of the vibration generating activities. As with vibration created from train operations, construction-related vibration rarely causes structural damage to normal building structures. However, some building damage can occur when construction-related activities are near older, more fragile buildings. As a result, construction-related vibration impact criteria give special consideration to these more fragile buildings.

VIBRATION SOURCE

The highest vibration levels typically generated by a freight train pass-by are from the locomotive itself. In general, train pass-by vibration levels are directly related to the weight of both the locomotive and the freight cars; heavier trains traveling at the same speed and on the same tracks will produce higher vibration levels. Note that factors such as speed, stiff primary suspension on the vehicle, and flat or worn wheels will increase the potential for ground-borne vibration.

Train weight was evaluated and was not modified for assessing vibration impacts during future operations. Locomotives are the heaviest component of a freight train. Modern 6-axle freight locomotives generally weigh 210 to 216 tons. Changes in locomotive weight or the number of locomotives utilized per train are not anticipated.

Replacing the tunnel will introduce double stacked intermodal container operations to this segment of the rail network. However, industry data for the rail industry indicates that intermodal containers are one of the lightest classes of freight shipped by rail. Most sizes or types of intermodal containers have a maximum allowable weight of 19 to 22 tons. Data from the Association of American Railroads (AAR) shows that freight railcars transporting intermodal containers have an average weight of 15 tons. By comparison numerous other commodities shipped by rail are heavier according to AAR data. This includes:

- Food and Food Products 65 tons per freight car
- Lumber & Wood Products 78 tons per freight car
- Grain 95 tons per freight car
- Sand and Gravel 101 tons per freight car
- Coal 116 tons per freight car

Freight trains comprised of double-stacked intermodal containers will weigh less than many of the current trains currently utilizing the Virginia Avenue Tunnel.

The length of the train is not a major factor when evaluating possible building damage. However, while peak vibration intensity is typically not higher for longer trains, they can cause greater annoyance due to the duration of the event.

Finally, the height of the freight car also does not directly influence the vibration intensity; double-stack freight cars do not produce higher vibrations just because they are carrying two containers.

3 IMPACT CRITERIA

This section presents the guidelines, criteria, and regulations that were used to assess vibration impacts associated with the proposed project. The District of Columbia Department of Transportation (DDOT) environmental regulations do not address potential vibration impacts; therefore, the criteria in the FTA *Transit Noise and Vibration Impact Assessment* (FTA 2006) were used to evaluate vibration impacts from tunnel construction and train operations. The evaluation of vibration impacts can be divided into two categories: (1) human annoyance and (2) building damage.

3.1 OPERATION VIBRATION IMPACT CRITERIA

HUMAN ANNOYANCE CRITERIA

Table 3-1 presents the human annoyance criteria for various land use categories by frequency of events. The criteria establish the limits beyond which ground-borne vibration would cause human annoyance or interfere with the use of vibration sensitive equipment. The criteria are expressed in terms of RMS velocity levels. PPV has been added to this table to allow for an easier comparison with the measured data for this project (which is described further in Chapter 4).

Table 3-1. Land Use Categories and Metrics for Rail Vibration Impact Criteria

LAND USE CATEGORY	GROUND-BORNE VIBRATION IMPACT LEVELS PPV AND VdB [5]					
	FREQUENT EVENTS[1]		OCCASIONAL EVENTS[2]		INFREQUENT EVENTS[3]	
Category 1: Buildings where vibration would interfere with interior operations.	0.007 in/sec	65 VdB[4]	0.007 in/sec	65 VdB[4]	0.007 in/sec	65 VdB[4]
Category 2: Residences and buildings where people normally sleep.	0.016 in/sec	72 VdB	0.023 in/sec	75 VdB	0.040 in/sec	80 VdB
Category 3: Institutional land uses with primarily daytime use.	0.023 in/sec	75 VdB	0.032 in/sec	78 VdB	0.056 in/sec	83 VdB

Source: FTA, 2006.

Notes:

1. "Frequent Events" is defined as more than 70 vibration events per day.
2. "Occasional Events" is defined as between 30 and 70 vibration events of the same source per day.
3. "Infrequent Events" is defined as fewer than 30 vibration events per day.
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, such as MRI or electron microscopes, would require detailed evaluation to define acceptable vibration levels.
5. The vibration reference level used to calculate VdB is 1 micro-inch per second.

There are some buildings that can be sensitive to vibration and noise, but do not fit into any of the three categories listed in Table 3-1. Because of the sensitivity of these buildings, they usually warrant special attention. **Table 3-2** provides criteria for acceptable levels of ground-borne vibration for various types of special buildings.

Table 3-2. Ground-Borne Vibration Criteria for Special Buildings

TYPE OF BUILDING OR ROOM	GROUND-BORNE VIBRATION IMPACT LEVELS PPV AND VdB [3]			
	FREQUENT[1] EVENTS		OCCASIONAL OR INFREQUENT EVENTS[2]	
Concert or Band Halls, TV Studios, Recording Studios	0.007 in/sec	65 VdB	0.007 in/sec	65 VdB
Auditoriums, Theaters	0.016 in/sec	72 VdB	0.040 in/sec	80 VdB

Source: FTA, 2006.

Notes:

1. "Frequent Events" is defined as more than 70 vibration events per day.
2. "Occasional or Infrequent Events" is defined as fewer than 70 vibration events per day.
3. The vibration reference level used to calculate VdB is 1 micro-inch per second.

BUILDING DAMAGE CRITERIA

The effects of ground-borne vibration include detectable movement of building floors, rattling of windows, shaking of items on shelves or hanging on walls, and rumbling sounds. It is extremely rare for vibration from train operations to cause any sort of building damage, even minor cosmetic damage (FTA 2006). However, there is sometimes concern about damage to fragile buildings located near the right-of-way. Accordingly, for the evaluation of vibration impacts, the FTA provides for typical train operations a vibration damage threshold criterion of 0.50 in/sec PPV for typical buildings and 0.12 in/sec PPV for fragile buildings (FTA 2006).

3.2 CONSTRUCTION IMPACT CRITERIA

Construction activities can result in varying degrees of ground vibration, depending on the equipment and methods employed. The vibration associated with this construction project will result from the following activities: demolition, excavation, and shoring of a tunnel. The construction vibration is generally assessed in terms of PPV. **Table 3-3** summarizes the construction vibration limits shown in FTA guidelines (FTA 2006).

Table 3-3. Construction Vibration Building Damage Criteria

BUILDING CATEGORY	PPV (IN/SEC)	VdB
I. Reinforced-concrete, steel, or timber (no plaster)	0.5	102
II. Engineered concrete and masonry (no plaster)	0.3	98
III. Non-engineered timber and masonry buildings	0.2	94
IV. Buildings extremely susceptible to vibration damage	0.12	90

Source: FTA, 2006.

4 EXISTING SETTING AND MEASUREMENT METHODOLOGY

4.1 EXISTING LAND USE

All of the candidate build alternatives would replace the existing 3,800-foot tunnel underneath Virginia Avenue SE, and include an additional 330-foot extension for the proposed location of the new east portal providing further protection to vibration sensitive land use areas and buildings currently located to the west of the existing portal location. For the purpose of this study, vibration sensitive receptors were selected based on their proximity to the three candidate build alternative alignments and based on existing land use, as described in the following paragraphs.

The Southeast/Southwest Freeway (I-695), located on the north side of the VAT, serves as a "barrier" that creates a discontinuity in vibration path from the proposed project to any sensitive receptors located to the north of the freeway. As a result there will be no vibration impacts from the construction or the trains operations of the proposed project at any of the buildings located north of I-695.

The following is a list of potentially vibration sensitive buildings from east to west that are located south of the proposed project and could be affected by the construction and/or by train operation vibrations:

- 809 Virginia Avenue - office building
- Marine Barracks, which includes the Enlisted Men's Quarters and the Marine Band Practice Hall - residential/special building (auditorium)
- Capper Senior Apartments – residential
- St. Paul African Union Methodist Protestant Church - institutional
- Capitol Quarter Townhomes – residential
- 200 I Street - institutional

There are other residential buildings as well as schools, hospitals, religious organizations, and similar institutions in the project vicinity but they are further away from the proposed project limits than the facilities noted above. **Figures 2** through **4 in Appendix A** show the location of the proposed Alternative 3 tunnel and the nearby buildings; these represent the condition with the closest track alignment adjacent to the sensitive receptors.

4.2 VIBRATION MEASUREMENT METHODOLOGY

Vibration measurements were conducted to determine baseline vibration levels from existing train pass-bys and to calculate vibration transferability characteristics of the soil for the purpose of projecting expected vibration levels during construction and from train operations. Vibration propagation is highly dependent on the soil, discontinuities in the path by which vibration travels, and the type of building foundation. Measuring the vibration levels from trains passing through the existing tunnel provides the most definitive information on how vibration is propagated in the surrounding area of the project.

The purpose of the measurements was to determine the force generated by train pass-bys, calculate soil vibration transferability characteristics, and predict tunnel vibration reduction effects. Measurements conducted near the east portal were the closest locations to the tracks where the strongest vibration signal could be measured without interference from the tunnel or other obstructions. Results of these measurements were suitable for calculating the soil vibration transferability characteristics and determining the highest train pass-by vibration level. Using the soil factor and train generated vibration levels, vibration effects could be calculated at various measurement sites near the tunnel. Therefore, differences between the measured and calculated vibration levels at a given site will provide the amount of the vibration reduction provided by the tunnel at that location. Knowing the vibration created by a train pass-by, soil factor, and tunnel vibration reduction amount, vibration levels can be predicted from the future tunnel at different locations.

Measurements were conducted near the tunnel on two separate occasions: between May 22 and 23, 2012 and between December 19 and 20, 2013. The vibration measurements were conducted using GeoSonic 3000EZ Plus and 3000LC portable seismographs. Vibration levels were measured on the vertical, transverse, and longitudinal axes and recorded as PPV vibrations (in inches per second). The seismograph includes an internal calibration sequence and was operated according to the manufacturer's specifications. Vibration measurements were conducted by Parsons staff.

Table 4-1 presents the list of measurement sites and **Figure 1** in **Appendix A** shows the general location of the sites. **Figures 2** through **4** in Appendix A show the measurement sites overlaid on an aerial background with the Alternative 3 track alignments and the nearby buildings. Note that Alternative 3 represents the condition with the closest track alignment to adjacent sensitive receptors.

Vibration levels at each location were measured for at least five train pass-bys. During each measurement, the speed of the train was recorded near the east portal using a radar gun and the number of locomotives as well as number of cars was recorded for each train. Baseline vibration levels collected just before and after each train pass-by during the day at each site were also recorded at each measurement site.

Three measurement probes were left overnight at the Marine Building 25 and Band Practice Hall (Room G62 in Building 25) locations because it was not feasible to gain access to them during the afternoon. Additional train pass-bys were recorded by the two probes outside of Marine Building 25 and the one probe near the Practice Hall before they were picked up on the morning of May 23, 2012.

Table 4-1. Vibration Measurement Sites

SITE NO	DATE	MONITORING LOCATION DESCRIPTION	DISTANCE TO THE EXISTING TRACK CENTER LINE (FEET)	PROPERTY USE
1	May 2012	Approximately 375 feet east of the east portal	19	Right-of-Way
2	May 2012	Approximately 375 feet east of the east portal	74	Right-of-Way
3	Dec 2013	Approximately 250 feet east of the east portal	28	Right-of-Way
4	Dec 2013	Approximately 250 feet east of the east portal	60	Right-of-Way
5	May 2012	Marine Building 25 [2]	61	Residential
6	May 2012	Marine Building 25 [3]	127	Residential
7	May 2012	Marine Building 25 - inside a closet across the hallway from the Practice Hall (Room G62)[1]	150 (approximate)	Band Practice Hall (auditorium)
8	Dec 2013	Capper Senior Apartments [2]	25	Residential
9	Dec 2013	Capper Senior Apartments [2]	68	Residential
10	Dec 2013	St. Paul African Union Methodist Protestant Church [2]	179	Church
11	May 2012	Capitol Quarter Townhomes [2]	40	Residential
12	May 2012	Capitol Quarter Townhomes [2]	73	Residential

Notes:

1. This location was chosen instead of a location inside the Practice Hall to avoid interference from the vibration levels created by the activities within the Practice Hall itself.
2. Grassy area between Virginia Avenue SE and the building
3. Grassy area adjacent to Marine Building 25

The four measurement probes at the Capper Senior Apartments and near the east portal were left overnight. Additional train pass-bys were recorded by these probes before they were picked up on the morning of December 20, 2013.

Table 4-2 shows a summary of the measurement results for the train pass-bys recorded on May 22, 2012 and December 19, 2013. Vibration Summary

Measurement results show that even though train vibration levels could be as high as 0.063 in/sec close to the tracks near the east portal, these levels drop almost by half at the closest buildings to the tracks. The majority of the measured train pass-by vibration levels were less than 0.020 in/sec at the closest buildings. The recorded reductions in vibration are due to the distance the building is located from the tunnel and the reduction provided by the existing tunnel structure.

Figure 4-1 shows results of the vibration measurements near Marine Building 25 (Site 6). The highest train pass-by vibration levels at this measurement site are approximately 0.010 in/sec which are several orders of magnitude below the FTA human annoyance impact limit of 0.040 in/sec. Measurement results indicate some non-train events are higher than the highest train pass-by vibration levels.

Figure 4-2 shows the measured interior data near the Marine Band Practice Hall, Room G62 in Building 25 (Site 7). The data revealed that the building's internal sources, such as the HVAC system, are a prevalent source of vibration. As shown in Figure 4-4, between 21:45 and 04:30, baseline measurements at Site 7 are much lower than baseline measurements outside this time range when the HVAC system was apparently on a lower setting. Some of the measured train vibration levels are higher than HVAC and other non-train generated vibration levels. At each train pass-by the measured cumulative vibration levels in the Practice Hall remained well below the FTA threshold of 0.040 in/sec for auditoriums in the special building category.

Table 4-2. Highest Train Pass-By and Non-Train Event Vibration Measurements

SITE NO	DATE	MONITORING LOCATION DESCRIPTION	DISTANCE TO EXISTING TRACK CENTER LINE (FEET)	PROPERTY USE	HIGHEST MEASURED TRAIN PASS-BY		HIGHEST MEASURED NON-TRAIN EVENT	
					PPV (IN/SEC)	VdB	PPV (IN/SEC)	VdB
1	May 2012	Approximately 375 feet east of the east portal	19	Right-of-Way	0.088	87	0.015	71
2	May 2012	Approximately 375 feet east of the east portal	74	Right-of-Way	0.050	82	0.008	66
3	Dec 2013	Approximately 250 feet east of the east portal	28	Right-of-Way	0.075	85	0.008	66
4	Dec 2013	Approximately 250 feet east of the east portal	60	Right-of-Way	0.038	80	0.008	66
5	May 2012	Marine Building 25 [2]	61	Residential	0.015	71	0.010	68
6	May 2012	Marine Building 25 [3]	127	Residential	0.010	68	0.013	70
7	May 2012	Marine Building 25 - inside a closet across the hallway from the Practice Hall (Room G62)[1]	150 (approximate)	Band Practice Hall (auditorium)	0.023 [4]	75 [4]	0.068 [4]	85 [4]
8	Dec 2013	Capper Senior Apartments [2]	25	Residential	0.045	81	0.028	77
9	Dec 2013	Capper Senior Apartments [2]	68	Residential	0.010	68	0.018	73
10	Dec 2013	St. Paul African Union Methodist Protestant Church [2]	179	Church	0.015	70	0.008	66
11	May 2012	Capitol Quarter Townhomes [2]	40	Residential	0.015	71	0.008	66
12	May 2012	Capitol Quarter Townhomes [2]	73	Residential	0.013	70	0.010	68

Notes:

1. This location was chosen instead of a location inside the Practice Hall to avoid interference from the vibration levels created by the activities within the Practice Hall itself.
2. Grassy area between Virginia Avenue SE and the building.
3. Grassy area adjacent to Marine Building 25.
4. Unknown activities occurred throughout the day in the Practice Hall in the vicinity of the closet containing the seismograph that combines with the measured vibrations of the trains.

Figure 4-3 shows the measured vibration levels near Capper Senior Apartments (Site 9) in December 2013. Spikes in the vibration levels indicate train pass-bys or other events. Non train pass-by measured events were identified to have occurred at the Capper Senior Apartments by comparing the actual logged train schedule and the recorded time of vibration spikes.

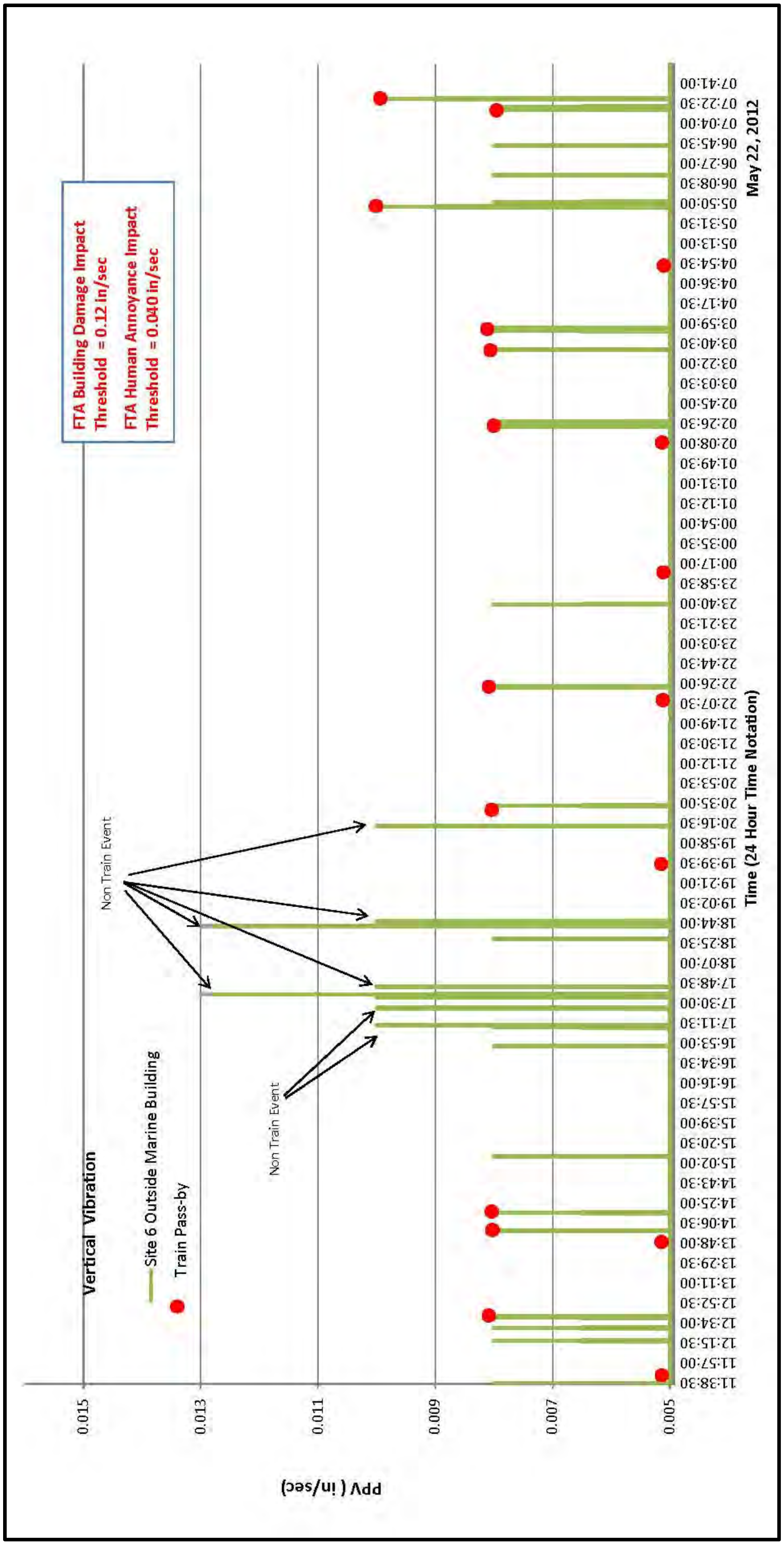


Figure 4-1. Existing Vertical Vibration Measurement near the Marine Building (Room G62 in Building 25)

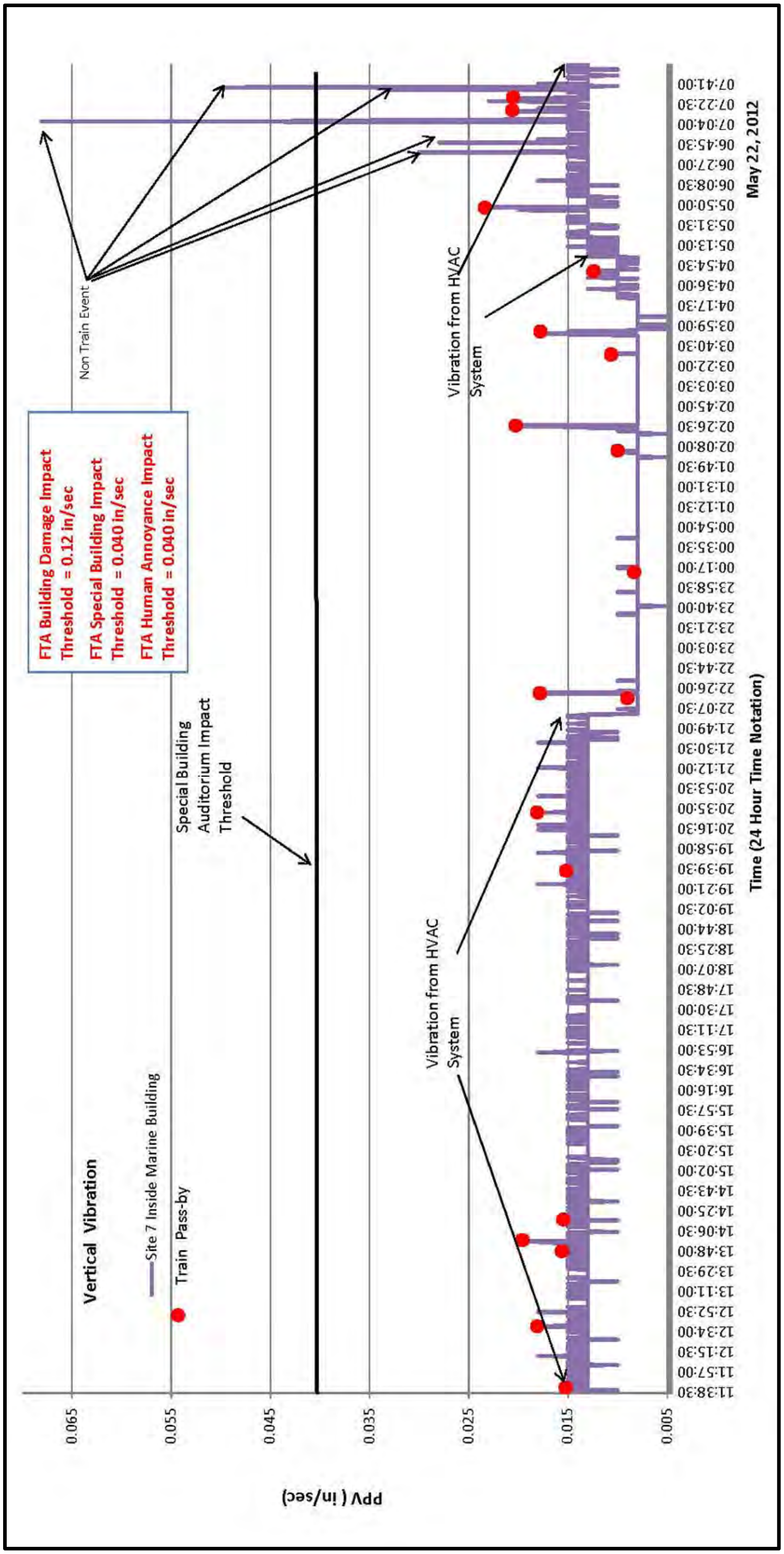


Figure 4-2. Existing Vertical Vibration Measurements at the Marine Band Practice Hall (Room G62 in Building 25)

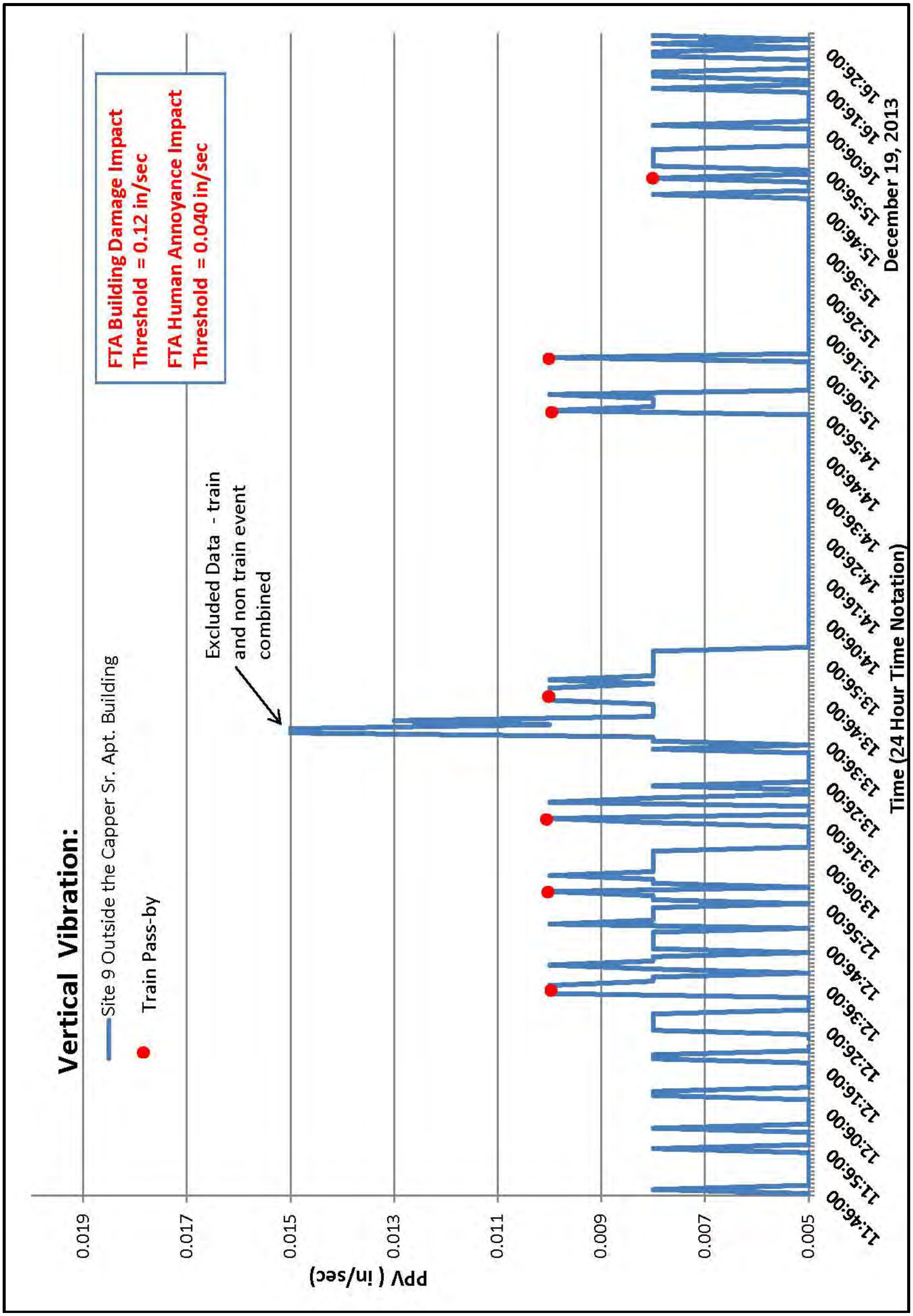


Figure 4-3. Existing Vertical Vibration Measurements near Capper Senior Apartments

Results indicate that the train pass-by is not the highest vibration source near the Capper Senior Apartments. As indicated in the graph in Figure 4-3, there were numerous non-train events that resulted in vibration levels as high as those recorded for train events. The highest train generated vibration levels were about 0.010 in/sec which are several orders of magnitude below the FTA human annoyance impact limit of 0.040 in/sec. Furthermore, these vibration levels would not be capable of causing cosmetic building damage or rattling windows at the Capper Senior Apartments.

Notably, a vibration level of 0.015 in/sec was recorded near the Capper Senior Apartments at 13:39 as a train was passing by. This vibration level is almost twice as high as other train pass-by measurements at that location. However, vibration measurements taken for the same train at the east portal of the existing tunnel showed vibration levels consistent with the recorded levels of other trains. As a result, it was determined that this single incident of high vibration at the Senior Apartments was an anomaly, produced by combination of the train pass-by and by another vibration-producing event in the neighborhood that caused this single aberrant recording. Accordingly, this one measurement was disregarded and not considered in the remainder of this analysis.

Figure 4-4 shows a typical single train pass-by, with measurements both at the portal and next to the Capper Senior Apartments (Site 9), along with two non-train vibration events recorded at the Senior Apartments. Typically each train pass-by produces several spikes depending on the train length. This set of data confirms that most of the vibration levels generated by trains passing by are about the same as vibration levels generated by other events near that building.

Figure 4-5 shows the train pass-by and baseline measurements at St. Paul African Union Methodist Protestant Church (Site 10). Measurements were between 0.005 and 0.015 in/sec (66 to 70 VdB), which is substantially less than the FTA threshold of 0.040 in/sec.

Figure 4-6 shows the measured existing vibration levels near the Capitol Quarter Townhomes (Site 12) indicating that the existing train pass-by vibration levels are nominally greater than the baseline levels. Yet all these levels are substantially below FTA limits for the human annoyance impact.

Recorded vibration levels do not demonstrate that vibrations from the existing train pass-bys are capable of causing structural or cosmetic damage at the nearby buildings. Measured vibration levels were well below the vibration damage threshold criterion of 0.50 in/sec for typical buildings and 0.12 in/sec for extremely fragile buildings.

In summary, the measured train pass-by vibration levels at the church, institutional and residential buildings closest to the tracks are barely perceivable; therefore, these levels are not capable of rattling windows, moving furniture, or causing building damages.

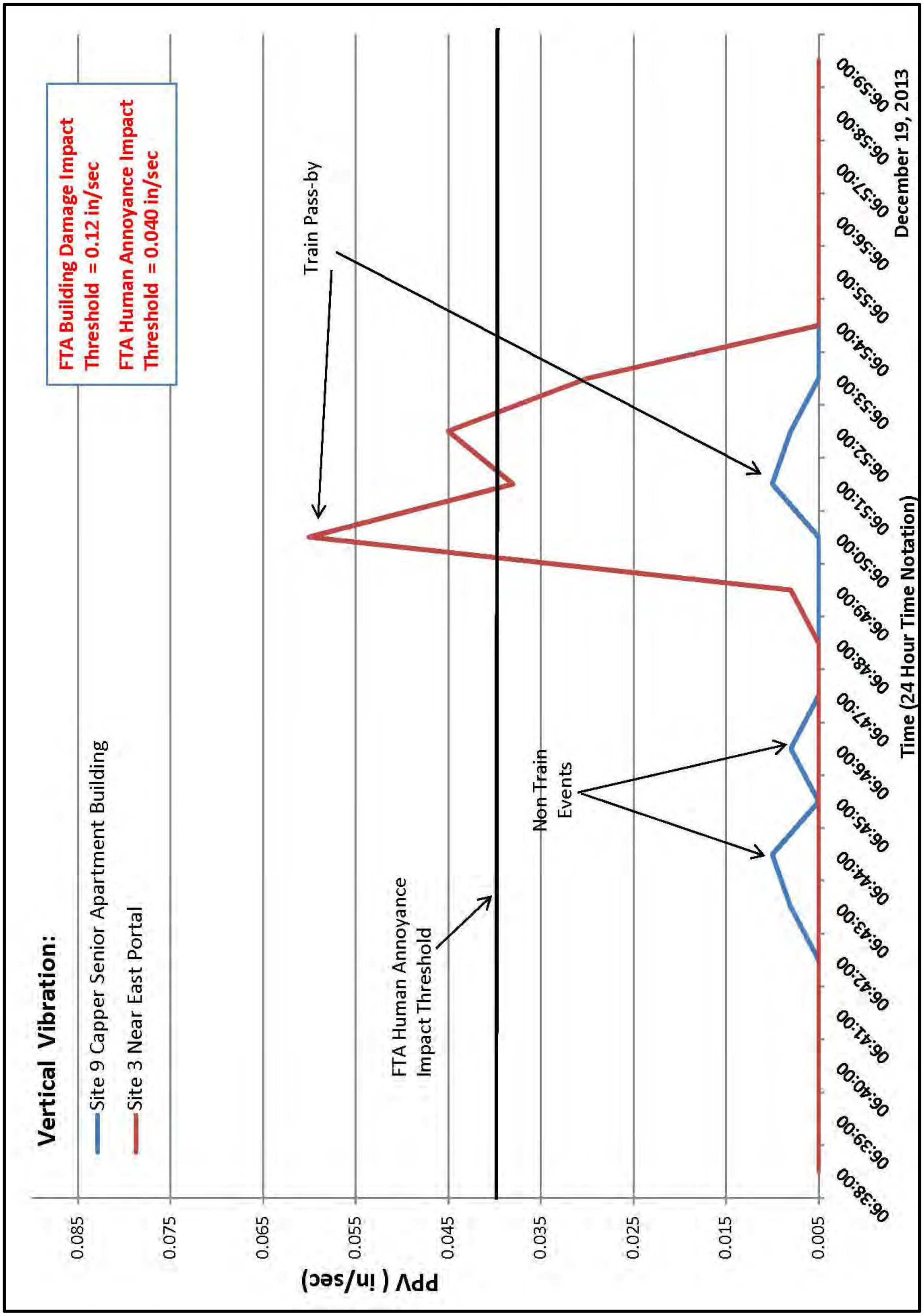


Figure 4-4. Single Train Pass-By Vertical Vibration Movement

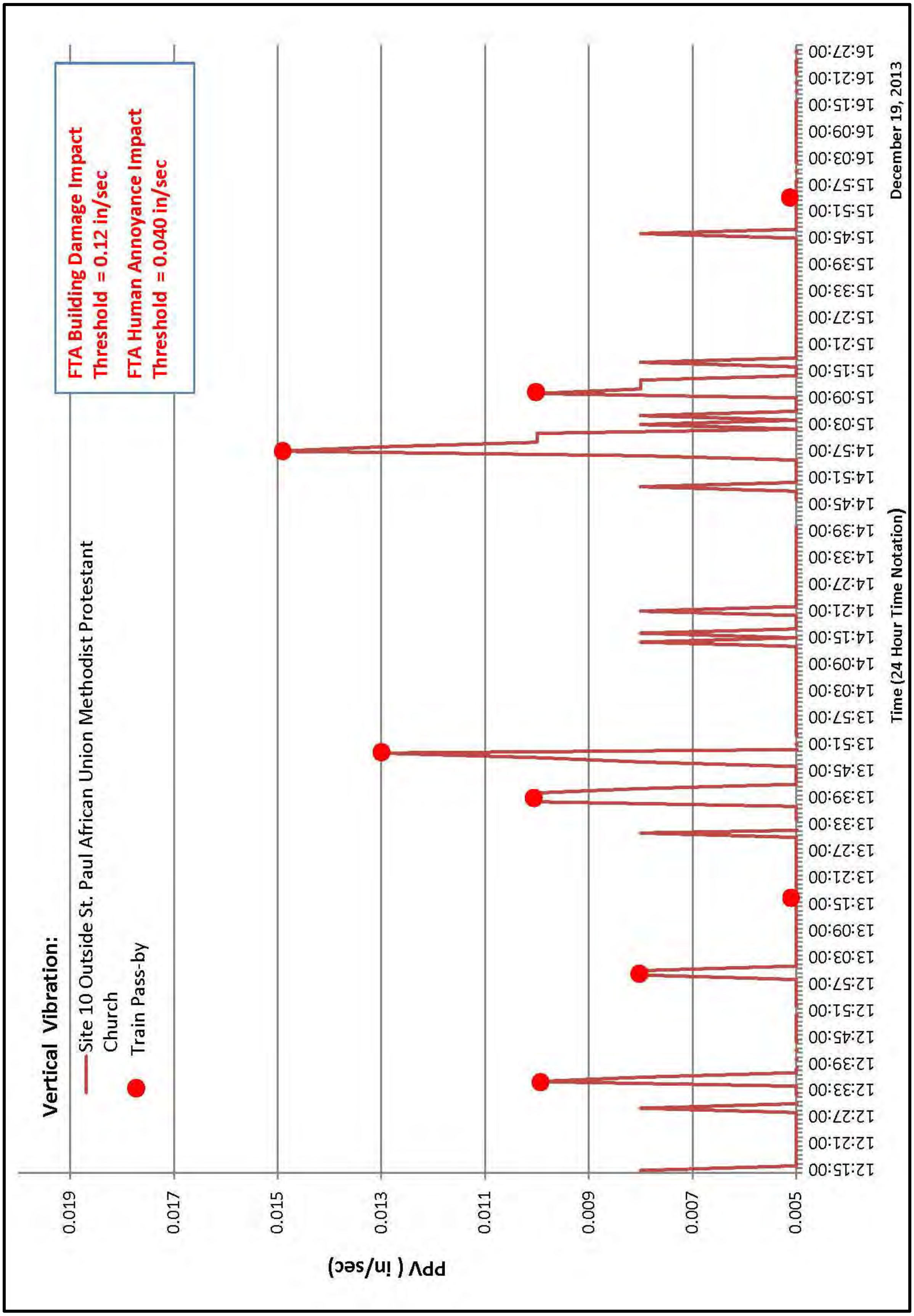


Figure 4-5. Train Pass-by and Baseline Measurements at St. Paul African Union Methodist Protestant Church

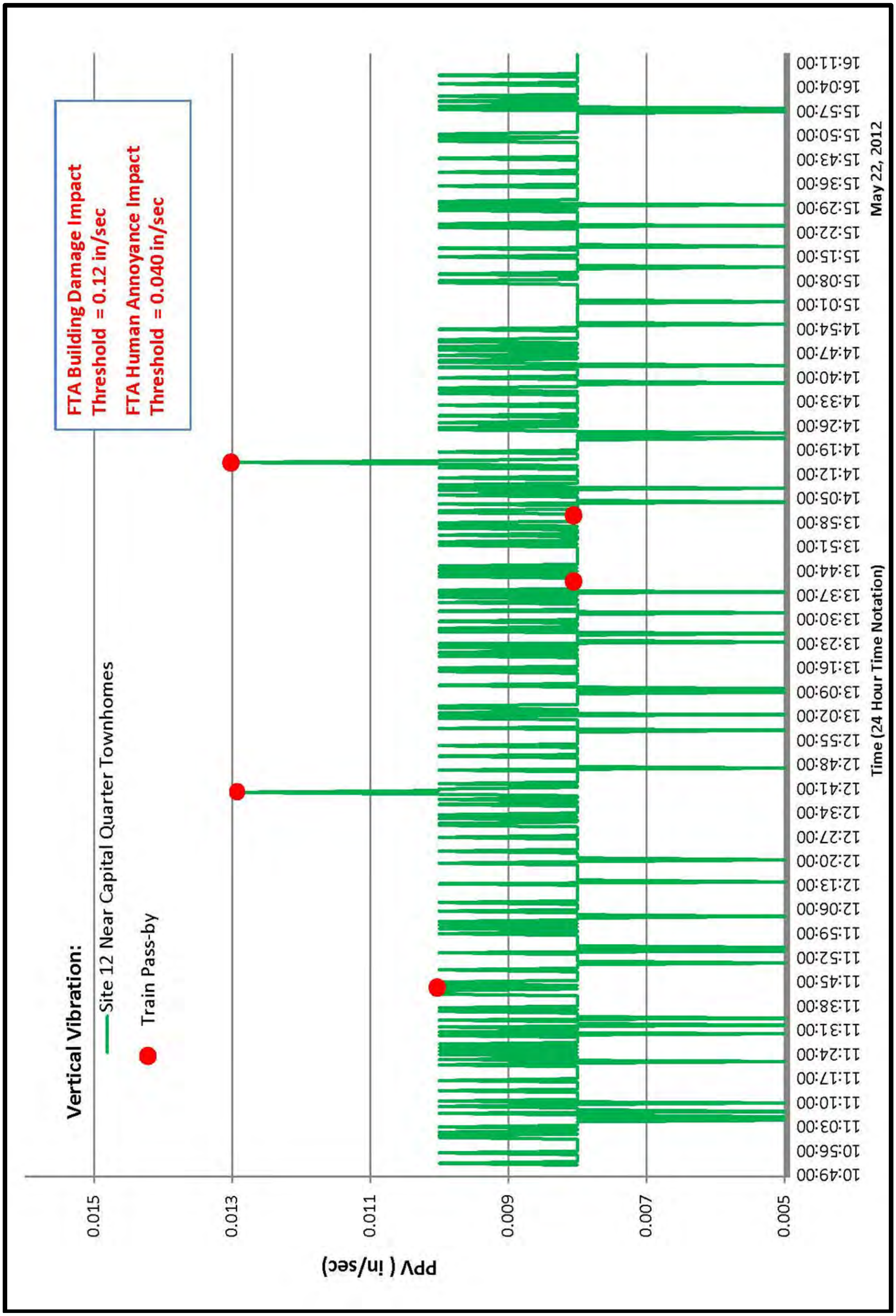


Figure 4-6. Existing Train Pass-By Vertical Vibration Measurements at the Capital Quarter Townhomes

4.3 SOIL PROPAGATION CHARACTERISTICS

The soil vibration propagation characteristic was calculated by comparing the PPV at different distances from the track. The east portal site was the most suitable location within the project area to measure the train tunnel pass-bys closest to the track; the data at this location is crucial in order to calculate the soil propagation characteristic. Results of measurements conducted in both May 2012 and December 2013 were used for calculating the soil vibration transferability characteristics.

It was determined from geotechnical field investigations conducted in support of the NEPA document by others (Mueser Rutledge Consulting Engineers) that the geology surrounding the proposed project area is similar and that the proposed tunnel base along the alignment would be founded on the same stratum of soils. Therefore, the calculated average soil factor from the measurements conducted near the east portal where they were unaffected by any tunnel structure reducing effects was used for the entire project area.

The vibration wave from the train pass-by dissipates as the wave transfers through the soil between two discrete points. This dissipation rate is dependent on the local soil composition and is called the soil factor in this report. The soil factors at the east portal vibration measurement site were calculated using recorded vibration levels at 30 second intervals for each train pass-by event. These values were then averaged to calculate the soil factor for the surrounding area of the project. **Table B-1** in **Appendix B** contains the data sets that were used to calculate the soil factor.

The vertical-axis results were used for this analysis, as recommended in the FTA manual (FTA 2006), because the vertical vibration is usually transmitted more efficiently into building foundations than transverse or longitudinal vibration.

5 IMPACT ASSESSMENT

Reconstruction of the Virginia Avenue Tunnel was evaluated to determine potential vibration impacts during the reconstruction project and from train operations. The impact assessment presented in this section was conducted in accordance with procedures outlined in FTA's *Transit Noise and Vibration Impact Assessment* manual (FTA 2006).

5.1 CONSTRUCTION VIBRATION

Two types of potential construction vibration impacts were analyzed: (1) human annoyance and (2) building damage. The potential for human annoyance occurs when construction vibration rises significantly above the threshold of human perception for extended periods of time. Building damage can be cosmetic or structural. As a general matter, fragile buildings such as older masonry structures have a greater potential to be susceptible to damage from ground vibration than buildings that are not particularly fragile (see Table 3-3 in Chapter 3).

Vibration levels produced by construction equipment were obtained from the FTA *Transit Noise and Vibration Impact Assessment* (FTA 2006). Based on the typical vibration levels for the various types of construction equipment expected to be used and as listed in **Table 5-1**, calculations were performed to determine the distances at which vibration impacts could occur during different activities and stages of the construction operations according to the FTA criteria discussed in Section 3.2.

Table 5-1. Ground-Borne Vibration Source Levels for Construction Equipment

EQUIPMENT	PPV AT 25 FEET (IN/SEC)	VdB AT 25 FEET
Large Bulldozer	0.089	87
Loaded Trucks	0.076	86
Hoe Ram	0.089	87
Caisson Drill	0.089	87
Sheet Driver (Sonic)	0.170	93
Jackhammer	0.035	79

Source: FTA, 2006

Vibration levels for the different construction activities were predicted using the best information available at the time the study was prepared. **Appendix C** contains a list of the equipment that most likely would be used during the different construction activities and their respective distances to each of the nearby buildings. **Table 5-2** shows in detail predicted vibration levels at nearby sensitive receivers from various construction activities that could create high vibration levels. There would be no structural vibration impacts due to construction operations under any of the candidate build alternatives. However, results in Table 5-2 indicate that there would be the potential for human annoyance impacts due to construction operations in accordance to the thresholds established in the FTA guidelines. It is anticipated that certain vibration producing construction activities would cause annoyance to the closest units of Capitol Quarter Townhomes and the Capper Senior Apartments. Vibration from certain construction activities may also exceed the FTA guidelines in the offices closest to the construction on the north side of the 200 I Street building. However no impacts are predicted for other more distant structures.

Vibration levels of 80 VdB (0.040 in/sec) and above have a potential to cause human annoyance in residential receptors according to FTA guidelines. Mitigation measures would need to be considered, if construction activities or equipment operating close to residential or institutional buildings are causing human annoyance. It is possible contractors may need to use different types of equipment for each activity instead of those used for predicting vibration in this study; therefore, vibration levels will be monitored during construction. If measurement results conducted during construction show that vibration levels exceed impact thresholds, construction methods will be reevaluated to reduce vibrations levels to below these thresholds.

Additional vibration from the train pass-bys in the open trench during the construction period for Alternative 2 was also considered and the assessment is presented in the following section as one of the project alternatives (see Table 5-3).

Table 5-2. Highest Construction Activity Vibration Levels

	809 VIRGINIA AVENUE		MARINE BUILDING		CAPPER SENIOR APARTMENTS		ST. PAUL AFRICAN UNION METHODIST PROTESTANT CHURCH		CAPITOL QUARTER TOWNHOUSES		200 I STREET	
CONSTRUCTION ACTIVITY	PPV (IN/SEC)	VdB	PPV (IN/SEC)	VdB	PPV (IN/SEC)	VdB	PPV (IN/SEC)	VdB	PPV (IN/SEC)	VdB	PPV (IN/SEC)	VdB
Utility Relocation	0.009	67	0.002	52	0.021	74	0.001	45	0.025	76	0.025	76
Surface Demolition	0.008	66	0.002	54	0.069	85	0.017	73	0.035	79	0.015	71
Existing Tunnel Demolition	0.010	68	0.003	59	0.014	71	0.002	53	0.017	72	0.017	73
Support of Excavation	0.029	77	0.006	63	0.061	84	0.003	57	0.070	85	0.070	85
Excavation	0.027	77	0.006	63	0.057	83	0.003	57	0.065	84	0.065	84
Tunnel Structure Construction	0.026	76	0.006	63	0.053	82	0.003	56	0.061	84	0.061	84
Backfill	0.027	77	0.006	63	0.057	83	0.003	57	0.065	84	0.065	84
Roadway Construction	0.017	73	0.004	60	0.061	84	0.003	56	0.021	74	0.033	78
Sheet Pile (Alt 4 Only)	0.021	74	0.007	64	0.029	77	0.004	59	0.034	79	0.036	79

Note: Because of the sensitivity of numbers, actual calculated/measured PPV values were used up to five decimals to convert from PPV to VdB. While PPV numbers shown in the table are rounded to 3 decimals and VdB to nearest full number.

5.2 TRAIN OPERATION VIBRATION

Train operational vibration assessment was conducted using FTA procedures and impact criteria along with the measured data collected close to the tracks (source) and at nearby vibration sensitive sites (receivers) within the project area. As described in Section 1.2, the three build alternatives include one tunnel with two tracks, two tunnels with one track in each tunnel, and a partitioned tunnel with two single tracks.

Measured vibration levels from the existing train pass-bys at different locations were used to calculate soil vibration transferability characteristics, the highest vibration levels generated by the train, and tunnel structure vibration reduction effects. These values were then used to predict the future train pass-by vibrations impacts at various nearby sensitive locations.

Descriptions of the source of vibration from a freight train, the potential effects of the new tunnel on reducing vibration, and a summary of the parameters that were utilized to predict vibration levels associated with train pass-bys are presented in this section. Finally, the results of the impact assessment are provided, including the impact distances for existing and future ground-borne vibration from train pass-bys.

EFFECTS OF THE NEW TUNNEL

The majority of track structure within the existing tunnel is sitting on dirt, while the proposed track structure within the new tunnel will be supported by a 3-foot thick reinforced concrete floor. A large mass such as the 3-foot thick concrete slab would reduce the vibrational energy generated by train pass-bys. Vibration levels at sensitive receptors would therefore be less from the new tunnel with its integral reinforced concrete floor in comparison to the existing tunnel with a natural earth floor. In addition the proposed use of a ballasted track section on top of the floor instead of directly attaching the tracks to the concrete floor slab, known as "direct fixation" has conservatively not been considered as well. The presence of ballast would serve to further reduce the vibrations reaching the soils below the floor slab. An exact vibration reduction effect for the proposed tunnel features cannot be determined from standard vibration modeling or from a review of published research data.

Despite the use of these techniques, future train vibration levels were predicted assuming a natural dirt floor that transmits more vibration energy into the surrounding soil in order to predict worst-case vibration levels. Vibration reduction effects of the new concrete walls were also not considered in the calculation; therefore, it can be expected that actual vibration levels would be substantially less than those estimated herein at receiver locations.

Is summary, as the tunnel adjustment factors (described further below) were determined from the measurements collected as part of this study, they would be lower than what is expected from measurements associated with the new tunnel.

ASSUMPTIONS AND ADJUSTMENTS TO VIBRATION PARAMETERS

The following are list of assumptions that were made in order to calculate vibration levels from the Virginia Avenue Tunnel:

- Train Speed: Train operation vibration is typically higher when trains are traveling at higher speeds. The strength of ground-borne vibration reduces or increases approximately as much as 20 times the logarithm of the speed ratio of existing speed and proposed speed. This means that doubling the train speed will increase vibration levels approximately 6 VdB. Existing measured peak vibration levels were for a train travelling at an average speed of 20 mph; however, trains in the proposed tunnel would be traveling at a maximum speed of 40 mph. Therefore, a **speed adjustment factor of an additional 6 VdB was applied to predict the future train pass-by vibration levels**.

- Building Category: In determining the potential vibration impact distance, the **lower limit of 0.012 in/sec specified by FTA for fragile buildings was utilized** regardless of the type and age of the building (see Table 3-3). This is a conservative approach and has a safety factor built in.
- Train Vibration Source: The measured vibration levels at the east portal (Sites 1, 2, 3, and 4), which are the closest sites to the tracks without a tunnel structure or other interferences were used as the train source for calculating impact distances for the existing/no build alternative, temporary trench route for Alternative 2, and the three candidate build alternatives.
- Highest Vibration Levels: **The highest recorded vibration level was used as the train vibration source** in calculating the temporary trench alternative and the three candidate build concepts to ensure that future impact distances were not under predicted. One high train pass-by measured vibration was eliminated because it was determined that some unknown non-train vibration source occurred concurrently with the train generated vibration.
- Soil Disturbance: Soil to the south of the existing tunnel will be disturbed (excavated and replaced) up to the shoring line adjacent to the new south wall of the proposed tunnel. The remaining soils south of the shoring line will remain undisturbed. Along much of the alignment the area that will be disturbed is small in comparison to the amount of soil between the source (track) and the receivers (buildings). Therefore, the soil vibration transferability characteristics are predicted to be the same as they would be under existing conditions.
- Number of Trains: Vibration **impact predictions were prepared assuming two trains were traveling in the tunnel simultaneously**. This approach yielded the highest possible vibration impact resulting from train operations.
- Vibration Propagation: When a train is moving through a tunnel the vibration waves propagate less effectively from the tunnel floor to the ground surface than vibration waves generated by a train operating at grade (where vibration waves travel more effectively along the ground surface).

The following are list of assumptions that were made in order to calculate vibration levels from the proposed build alternatives for the reconstructed Virginia Avenue Tunnel:

- Proposed Track Alignment: An adjustment was applied to the measured vibration levels to account for a turnout near the east tunnel portal. This turnout will be eliminated once the new tunnel is constructed. Therefore, as per FTA guidelines, measured existing **vibration levels that are used for calculating future vibration levels were reduced by 5 VdB with the removal of the discontinuity in the track** represented by the turnout. This adjustment is needed to determine the vibration force generated by train pass-bys without the discontinuity which is then utilized for calculating the vibration effects from the trains in the new tunnel.
- Soil Factor: The **calculated soil factor** (see Section 4.2) was used as a parameter to adjust the rate that the vibration wave would decline in strength as it propagates away from the train.

- Tunnel Adjustment Factor: Using the train force strength measured near the tracks at Sites 1, 2, 3, and 4 and the calculated soil factor, vibration levels were calculated at the other measurement locations. All of the calculated levels were higher than the measured level. The differences between the calculated and measured levels can be attributed to the tunnel's vibration reduction characteristic. **Tables B-2** and **B-3** in **Appendix B** summarize the measured (with tunnel) and calculated (without tunnel) vibration levels for ten of the train pass-bys that were recorded in May 2012 and December 2013. Measurements from ten train pass-bys are sufficient for calculating a reliable tunnel adjustment factor. An averaged tunnel adjustment factor of 0.021 in/sec was derived from an analysis of both sets of data. This adjustment is for the existing tunnel and will be higher for the future tunnel due to the proposed integral reinforced concrete foundation which would provide a higher vibration reduction effect.

VIBRATION IMPACT DISTANCES

The outer calculated limit of vibration impact, when measured from the source of the vibration, is known as the impact distance. These vibration impact distances were calculated using the parameters and adjustments described in the preceding section. The impact distances for human annoyance for existing conditions and for each of the candidate build alternatives are shown in **Table 5-3**.

Table 5-3. Human Annoyance Impact Distances for Existing and Predicted Train Pass-Bys

ALTERNATIVES	DISTANCE TO POTENTIAL VIBRATION HUMAN ANNOYANCE (FEET)
Existing/ No Build	12
Alternative 2 (during construction when there is a Temporary Trench Route)	12
Alternative 2	30
Alternative 3	30
Alternative 4	30

Note: The vibration reduction effects of the ballasted track bed on an integral reinforced concrete floor slab were not considered in predicting the future vibration levels.

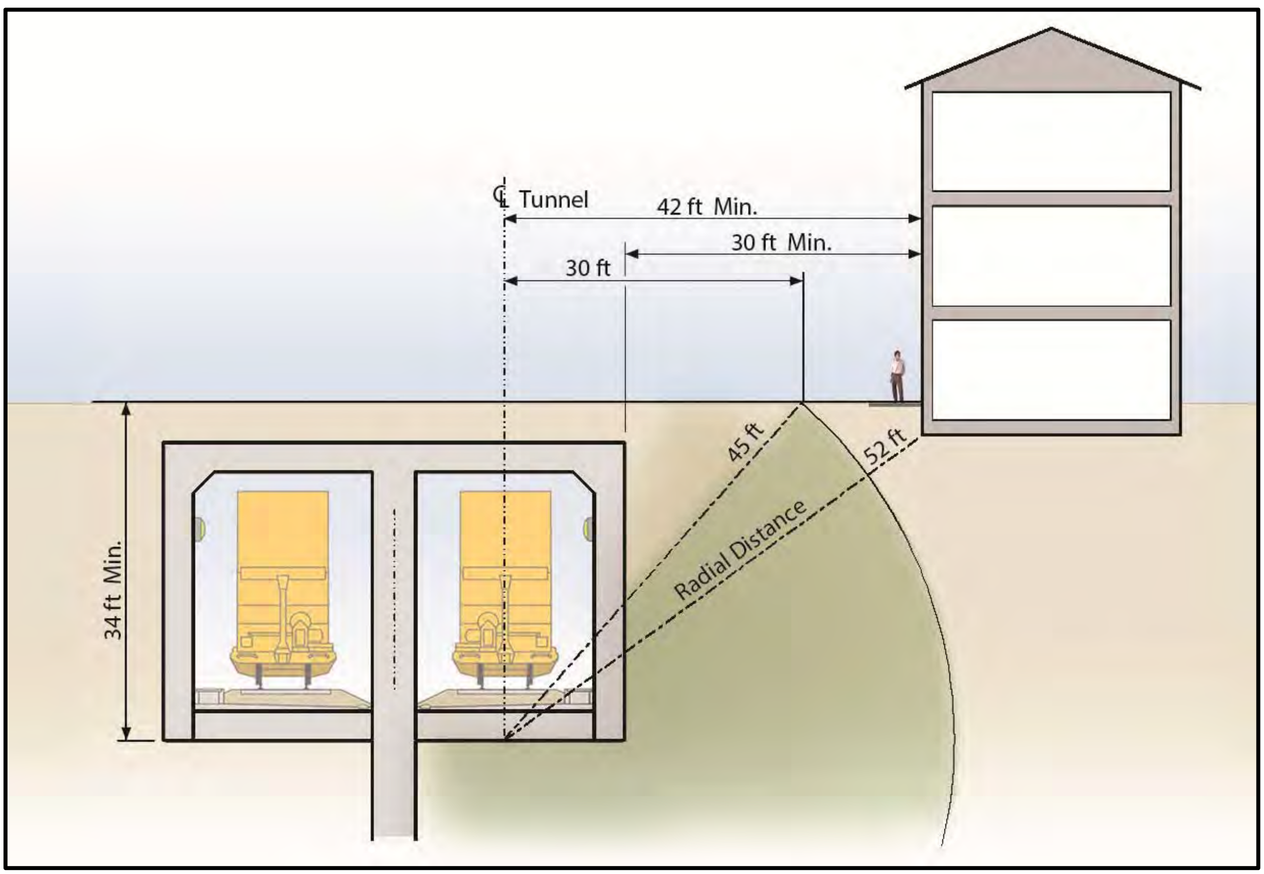
Table 5-4 shows that human annoyance impacts (as defined by FTA) from train pass-bys would not be experienced more than 45 feet away from the track under any of the candidate build alternatives, i.e., two trains using one tunnel with two tracks or using two tunnels with one track in each. The calculated annoyance distance of 45 feet from the track centerline is only true if the tracks were located at grade. However, because trains will be traveling in the tunnel, the 45 feet distance is a radial distance at which the vibration waves generated by a train will reach the ground surface. Therefore the human annoyance distance at the ground surface from the track centerline would be 30 feet. **Figure 5-1** shows this concept graphically.

Table 5-4. Impact Distances from Train Pass-Bys

LOCATION	MINIMUM HORIZONTAL DISTANCE TO SOUTHERNMOST TRACK (feet)[1]	RADIAL DISTANCE TO THE NEAREST TRACK (feet)[1]	ESTIMATED RADIAL DISTANCE TO VIBRATION POTENTIAL HUMAN ANNOYANCE (feet)[1]	HUMAN ANNOYANCE EXPECTED?	ESTIMATED RADIAL DISTANCE TO VIBRATION POTENTIAL BUILDING DAMAGE (feet)[1]	BUILDING DAMAGE EXPECTED?
809 Virginia Avenue	57	66	45	No	27	No
Marine Band Practice Hall	107	113	45	No	27	No
Capper Senior Apartments	44	52	45	No	27	No
St. Paul African Union Methodist Protestant Church	147	150	45	No	27	No
Capital Quarter Townhomes	42	52	45	No	27	No
200 I Street	42	50	45	No	27	No

Note:

1. Dimension from bottom of tunnel floor to grade at the face of adjacent building.
2. Predictions based on Alternative 3 which is the closest potential track to sensitive receptors



Note: While the primary vibration source will propagate from the base of the tunnel as the freight trains run along the tracks, secondary vibrations will radiate from the tunnel walls. The graphic depicts Alternative 3 which is the condition with the closest track alignment to the adjacent sensitive receptors.

Figure 5-1. Train Pass-By Vibration Levels

Figures 2 through **4** in **Appendix A** show the 30-foot human annoyance impact line from two trains operating in the tunnel at the same time. As there are no residential buildings located between the impact line and the southern track of Alternative 3 (the closest potential track to sensitive receptors), there would be no predicted vibration impact from future train operations.

Table 5-5 and **Table 5-6** provide a summary of the predicted level of ground borne vibration from construction and train operations, respectively, at each of the of the identified sensitive receptors along the tunnel alignment. The locations of all monitoring and prediction sites are shown in Appendix A – Figure 1. Note that some monitoring sites were selected to determine soil transferability characteristics and were not used for prediction sites (due to absence of receptors). For prediction purposes the offset distance, calculated PPV and VdB at the receptors and the controlling construction activity for Alternative 3 alignment was used as this represents the condition with the closest track alignment to the sensitive receptors. Further it should be noted that the estimated vibration levels shown on the tables do not consider the vibration reduction effect of the integral reinforced concrete floor, which would reduce the reported values for the peak estimated vibration levels shown in the tables.

Table 5-4 also shows that any building located 27 feet or more from the track centerline would not experience significant operational vibration impacts. As the tracks will be located a minimum of 34 feet underground with propagation paths (radial distances) of 52 to 150 feet for the receptor facilities along the corridor, no building damage is anticipated.

Table 5-5. Predicted Level of Ground Borne Vibration – Construction

MONITORING SITE NO	PROPERTY USE	LOCATION	FTA LAND USE CATEGORY	CONTROLLING CONSTRUCTION ACTIVITY [5]	DISTANCE (FEET) [5]	FTA LIMITS FOR HUMAN ANNOYANCE		FTA LIMITS FOR BUILDING DAMAGE		PEAK ESTIMATED VIBRATION LEVELS [5]		HUMAN ANNOYANCE IMPACT	BUILDING DAMAGE IMPACT
						PPV, IN/SEC	VdB [6]	PPV, IN/SEC	VdB [6]	PPV, IN/SEC	VdB [6]		
--	Institutional	809 Virginia Ave	3	Support of Excavation, Excavation, Backfill	43	0.056	83	0.120	90	0.029	77	No	No
6	Residential	Marine Building 25 [3]	2	Support of Excavation, Excavation, Tunnel Structure Construction, Backfill	93	0.040	80	0.120	90	0.006	63	No	No
7	Band Practice Hall (auditorium)	Marine Building 25 - inside a closet across the hallway from the Practice Hall (Room G62) [1]	N/A [1,4]	Support of Excavation, Excavation, Tunnel Structure Construction, Backfill	113	0.040	80	0.120	90	0.006	63	No	No
9	Residential	Capper Senior Apartments [2]	2	Surface Demolition	18	0.040	80	0.120	90	0.069	85	Yes	No
10	Church	St. Paul African Union Methodist Protestant Church [2]	3	Surface Demolition	35	0.040	80	0.120	90	0.017	73	No	No
12	Residential	Capitol Quarter Townhomes [2]	2	Support of Excavation	28	0.040	80	0.120	90	0.070	85	Yes	No
--	Institutional	200 I Street	3	Support of Excavation	28	0.056	83	0.120	90	0.070	85	Yes	No

Notes:

1. This location was chosen instead of a location inside the Practice Hall to avoid interference from the vibration levels created by the activities within the Practice Hall itself.
2. Grassy area between Virginia Avenue SE and the building.
3. Grassy area adjacent to Marine Building.
4. Categorized as a special building usage in Table 8-2 of “Transit Noise and Vibration Assessment,” FTA, 2006.
5. Alternative 3 has been used as it represents the condition with the closest track alignment adjacent to the sensitive receptors.
6. Because of the sensitivity of numbers, actual calculated/measured PPV values were used up to five decimals to convert from PPV to VdB. While PPV numbers shown in the table are rounded to 3 decimals and VdB to nearest full number.

Table 5-6. Predicted Level of Ground Borne Vibration – Future Train Operations

SITE NO	PROPERTY USE	LOCATION	FTA LAND USE CATEGORY	TRAIN SPEED (MPH)	RADIAL DISTANCE (FEET) [5]	FTA LIMITS FOR HUMAN ANNOYANCE		FTA LIMITS FOR BUILDING DAMAGE		PEAK ESTIMATED VIBRATION LEVELS [5]		HUMAN ANNOYANCE IMPACT	BUILDING DAMAGE IMPACT
						PPV, IN/SEC	VdB [6]	PPV, IN/SEC	VdB [6]	PPV, IN/SEC	VdB [6]		
--	Institutional	809 Virginia Ave	3	40	66	0.056	83	0.120	90	0.018	73	No	No
6	Residential	Marine Building 25 [3]	2	40	113	0.040	80	0.120	90	0.006	63	No	No
7	Band Practice Hall (auditorium)	Marine Building 25 - inside a closet across the hallway from the Practice Hall (Room G62) [1]	N/A [4]	40	150	0.040	80	0.120	90	0.003	58	No	No
9	Residential	Capper Senior Apartments [2]	2	40	52	0.040	80	0.120	90	0.030	78	No	No
10	Church	St. Paul African Union Methodist Protestant Church[2]	3	40	150	0.040	80	0.120	90	0.003	58	No	No
12	Residential	Capitol Quarter Townhomes [2]	2	40	52	0.040	80	0.120	90	0.030	78	No	No
--	Institutional	200 I Street	3	40	50	0.056	83	0.120	90	0.033	78	No	No

Notes:

1. This location was chosen instead of a location inside the Practice Hall to avoid interference from the vibration levels created by the activities within the Practice Hall itself.
2. Grassy area between Virginia Avenue SE and the building.
3. Grassy area adjacent to Marine Building.
4. Categorized as a special building usage in Table 8-2 of "Transit Noise and Vibration Assessment," FTA, 2006.
5. Alternative 3 has been used as it represents the condition with the closest track alignment adjacent to the sensitive receptors.
6. Because of the sensitivity of numbers, actual calculated/measured PPV values were used up to five decimals to convert from PPV to VdB. While PPV numbers shown in the table are rounded to 3 decimals and VdB to nearest full number.

6 MITIGATION

This section discusses potential mitigation measures that can be implemented to reduce or mitigate vibration impacts resulting from reconstruction of the Virginia Avenue Tunnel and future train operations.

6.1 CONSTRUCTION VIBRATION MITIGATION

It is possible that certain construction activities could cause intermittent localized concern from vibrations in the project area. Processes such as earth moving with bulldozers, the use of vibratory compaction rollers, and demolition could cause some human annoyance impacts. There are cases where it may be necessary to use this type of equipment in close proximity to residential buildings.

A vibration monitoring and mitigation plan will be prepared by a qualified vibration engineer prior to the start of construction. The plan would include vibration monitoring procedures at predetermined vibration sensitive sites, updated calculations of predicted vibration levels at the receptors based on measurements at the source of the actual construction activities, and recommendations for mitigation measures if they are needed based on the calculations. The plan will be a living document throughout construction and will be updated and submitted to DDOT should there be any major changes in findings, proposed mitigations or to the planned construction activities.

The plan would identify buildings that are candidates for pre- and post-construction surveys if they are close enough to a construction vibration source that may cause vibration impacts. The surveys would document the pre-construction condition of the structures in detail and final condition post construction. Findings if any, of damage as documented by the surveys would be addressed via the claims process which is described in the Environmental Impact Statement. Surveys would be conducted only with the permission of the owners of buildings.

The vibration monitoring and mitigation plan would also include, but not be limited to, the following items:

- The name and qualifications of the vibration specialist(s), who must have a Bachelor of Science or higher degree from a qualified program in engineering or physics offered by an accredited university or college, and at least 10 years of experience in vibration control engineering and vibration analysis. In addition to the basic requirements, vibration specialist must demonstrate substantial and responsible experience in conducting vibration measurements, calculating vibration propagation, as well as designing and overseeing the implementation of vibration abatement measures.

- The location of seismograph(s) placements on the existing and temporary tunnel, as well as nearby buildings, as directed by the vibration monitoring specialist.
- The scheduled start dates and length of construction operations that require vibration monitoring. There would be separate time intervals for each construction operation.
- The location of any sewer or water line in proximity to construction operations.
- Specifications of the seismograph including: the manufacturer's name, model number, and documentation of factory calibration performed within the preceding 12 months. The seismograph will be capable of measuring peak particle velocity (PPV) data in three mutually perpendicular directions.
- Appropriate detailed procedures for placing and operating the seismograph.
- The procedure for tracking PPV throughout construction operations (e.g., sonic piling and drilling operations).
- A record of the time of day when each monitored construction activity took place.

The following are procedures that can be used to minimize the potential for human annoyance from construction vibration:

- Conduct vibration monitoring during vibration-intensive activities.
- Properly maintain all motorized equipment in a state of good repair to limit wear-induced vibration.
- Where feasible, avoid the use of impact type pile driving near residences; instead use drilled piles or the use of a sonic or vibratory pile driver, which cause lower vibration levels (where the geological conditions permit their use).
- When there is a possibility of human annoyance from construction activities, such as the operation of vibratory rollers, absent urgent and unexpected circumstances, conduct such activity only during weekday daytime hours when the ambient background noise and vibration is higher and many residents are away from their homes at work.
- Develop a phasing plan so that high vibration generating activities do not occur within the same time period is close proximity to each other, to the maximum extent practicable.
- Avoid routing heavily-loaded trucks through densely concentrated residential areas, when ever reasonably possible within the approved maintenance of traffic plans.
- Where feasible, use demolition methods that do not involve use of high impact tooling such as hoe rams and use crushing style attachments instead.
- Avoid the use of large vibratory rollers and packers near sensitive areas, when possible and use smaller equipment with smaller lifts.

A combination of the noted mitigation techniques for equipment vibration control as well as administrative measures, when properly implemented, can be selected to achieve the most effective means to minimize the effects of construction activities. Application of the noted mitigation measures will reduce the construction impacts; however, temporary increases in vibration would likely occur at some locations during some construction activities. The extent of potential impacts cannot be determined until detailed construction work plans for each phase of the construction operations have been developed. Once known the vibration monitoring plan described above will be the principle tool for determining which measures will be most effective for each of the construction activities.

6.2 TRAIN OPERATION VIBRATION MITIGATION

As described in the results of the vibration impact analysis in Chapter 5, ground-borne vibrations are not predicted to exceed the FTA criteria for train operations under any of the candidate build alternatives; therefore, vibration mitigation would not be necessary.

Even though there would be no vibration impacts associated with the train operations, some design features have conservatively not been considered in the reports calculations and analysis that would in fact serve to further reduce the calculated train pass-by vibration levels if used. These features are:

- The presence of a proposed 3-foot thick reinforced concrete floor foundation for the tunnel.
- The use of a ballasted track section on top of the floor instead of directly attaching the tracks to the concrete floor slab. This will further reduce the vibrations reaching the soils below the floor slab.

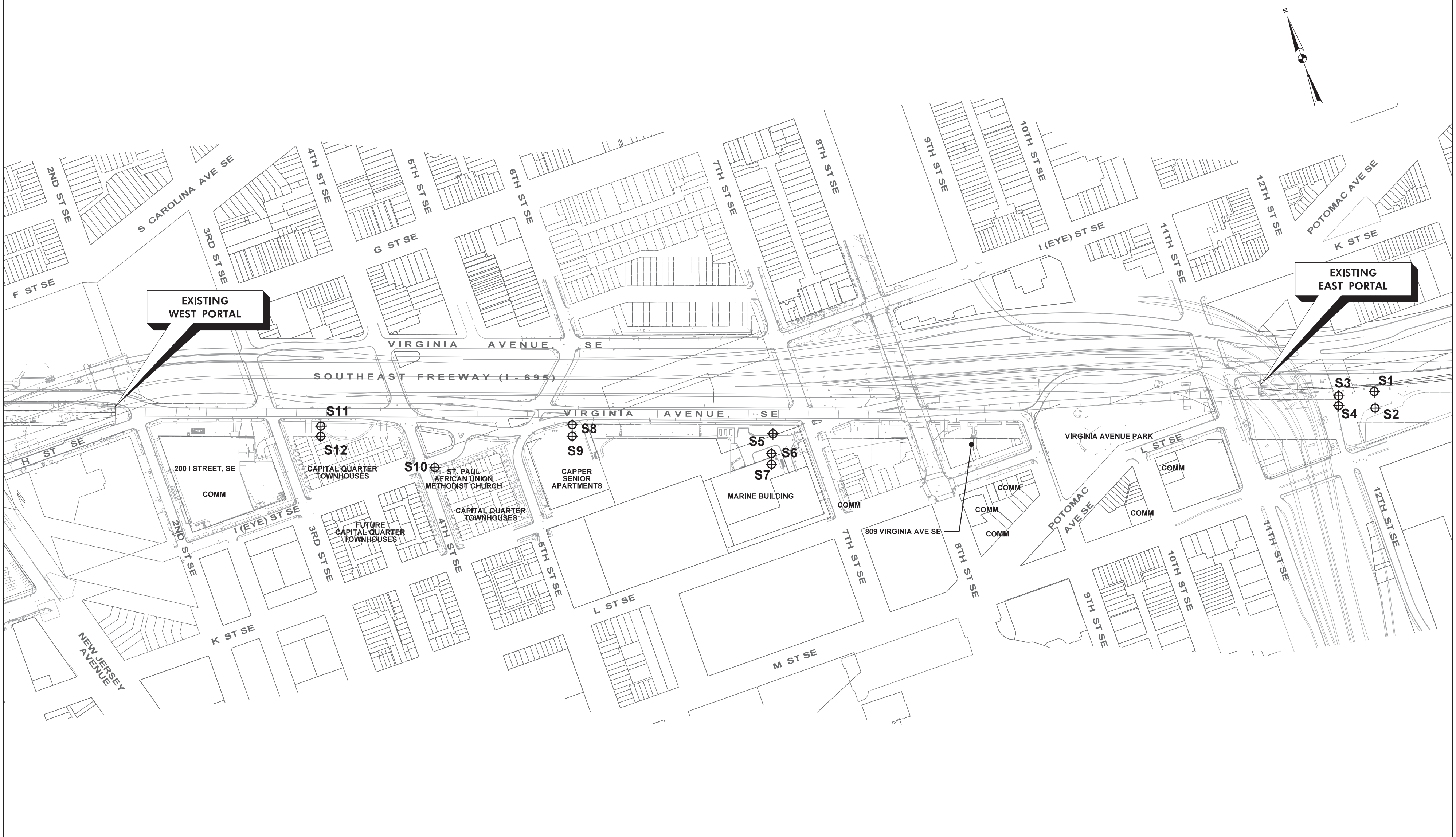
For areas where the estimated peak vibration levels for future train operations are close to the FTA limits (the 300 block and 500 block of Virginia Avenue) for human annoyance the introduction of a ballast mat in the southernmost tunnel on top of the concrete floor foundation prior to construction of the track bed would serve to further reduce the potential ground borne vibrations at the adjacent receptors.

Table 6-1 provides a summary of potential impacts and actions to potentially avoid or minimize them.

Table 6-1. Summary of Impact and Mitigation Measures

MITIGATION OF VIBRATION IMPACTS	CONSTRUCTION IMPACTS		TRAIN OPERATION IMPACTS	
	POTENTIAL BUILDING DAMAGE	POTENTIAL HUMAN ANNOYANCE	POTENTIAL BUILDING DAMAGE	POTENTIAL HUMAN ANNOYANCE
Avoidance	Yes	To the extent practical	Yes	Yes
Minimization	Not required since impacts are avoided	Yes	Not required since impacts are avoided	Not required since impacts are avoided
Repair or Restore	Not required since impacts are avoided	Not required since impacts are avoided	Not required since impacts are avoided	Not required since impacts are avoided
Reduce over Time	Not required since impacts are avoided	Not required since impacts are avoided	Not required since impacts are avoided	Not required since impacts are avoided
Compensate	Not required since impacts are avoided	Not required since impacts are avoided	Not required since impacts are avoided	Not required since impacts are avoided

A VIBRATION MEASUREMENT SITES



LEGEND

⌖ VIBRATION MEASUREMENT SITE

S12 VIBRATION MEASUREMENT SITE NUMBER

COMM COMMERCIAL

CLARK CONSTRUCTION PARSONS
100 M Street SE, Washington, DC 20003

VIRGINIA AVENUE TUNNEL

VIBRATION MEASUREMENT SITES

FIGURE 1

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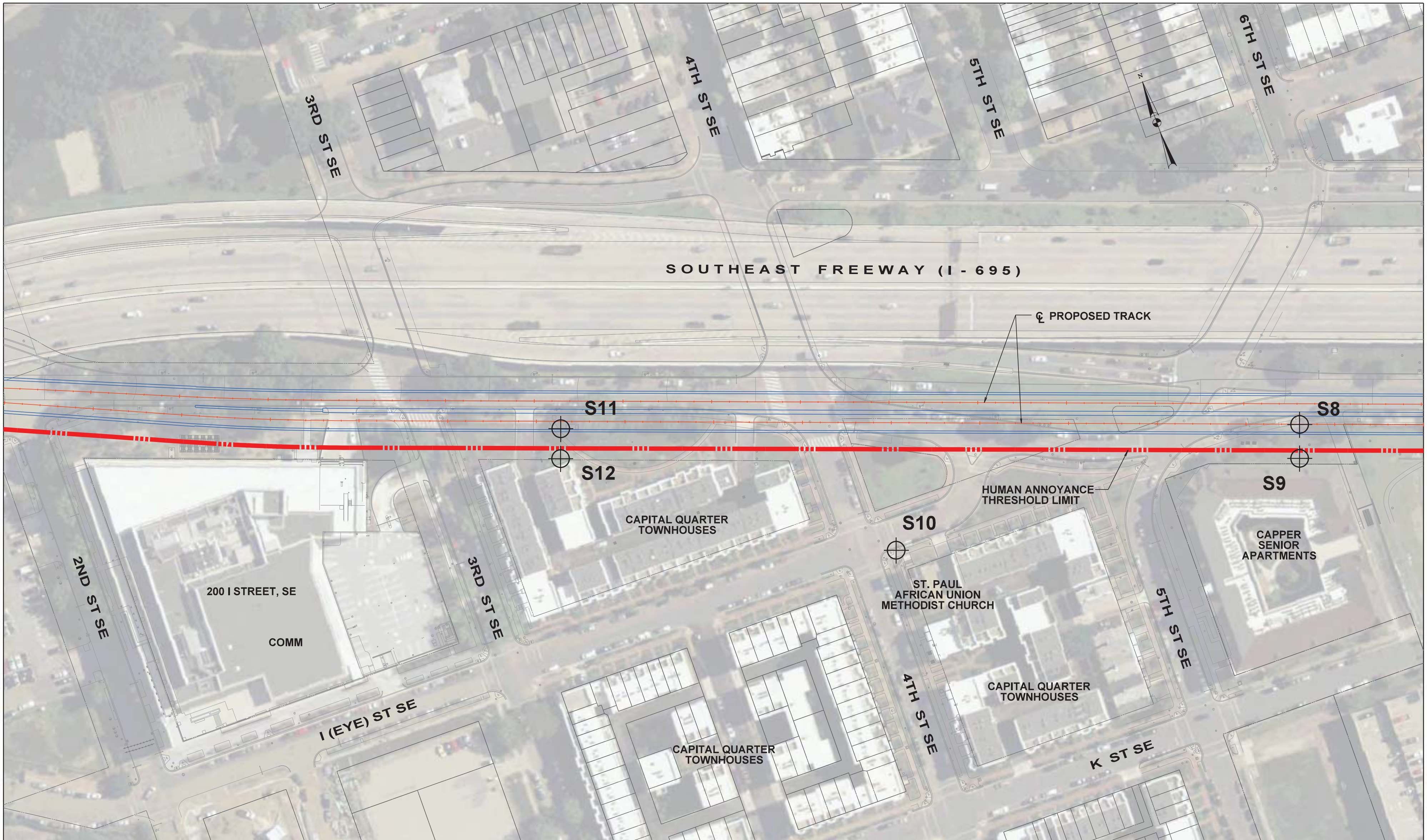

LEGEND

⌖	VIBRATION MEASUREMENT SITE	COMM	COMMERCIAL
S12	VIBRATION MEASUREMENT SITE NUMBER		℄ PROPOSED TRACK
	HUMAN ANNOYANCE IMPACT LINE		PROPOSED TUNNEL WALL

CLARK CONSTRUCTION
PARSONS
100 M Street SE, Washington, DC 20003

VIRGINIA AVENUE TUNNEL

VIBRATION MEASUREMENT SITES - ALTERNATIVE 3

FIGURE 2

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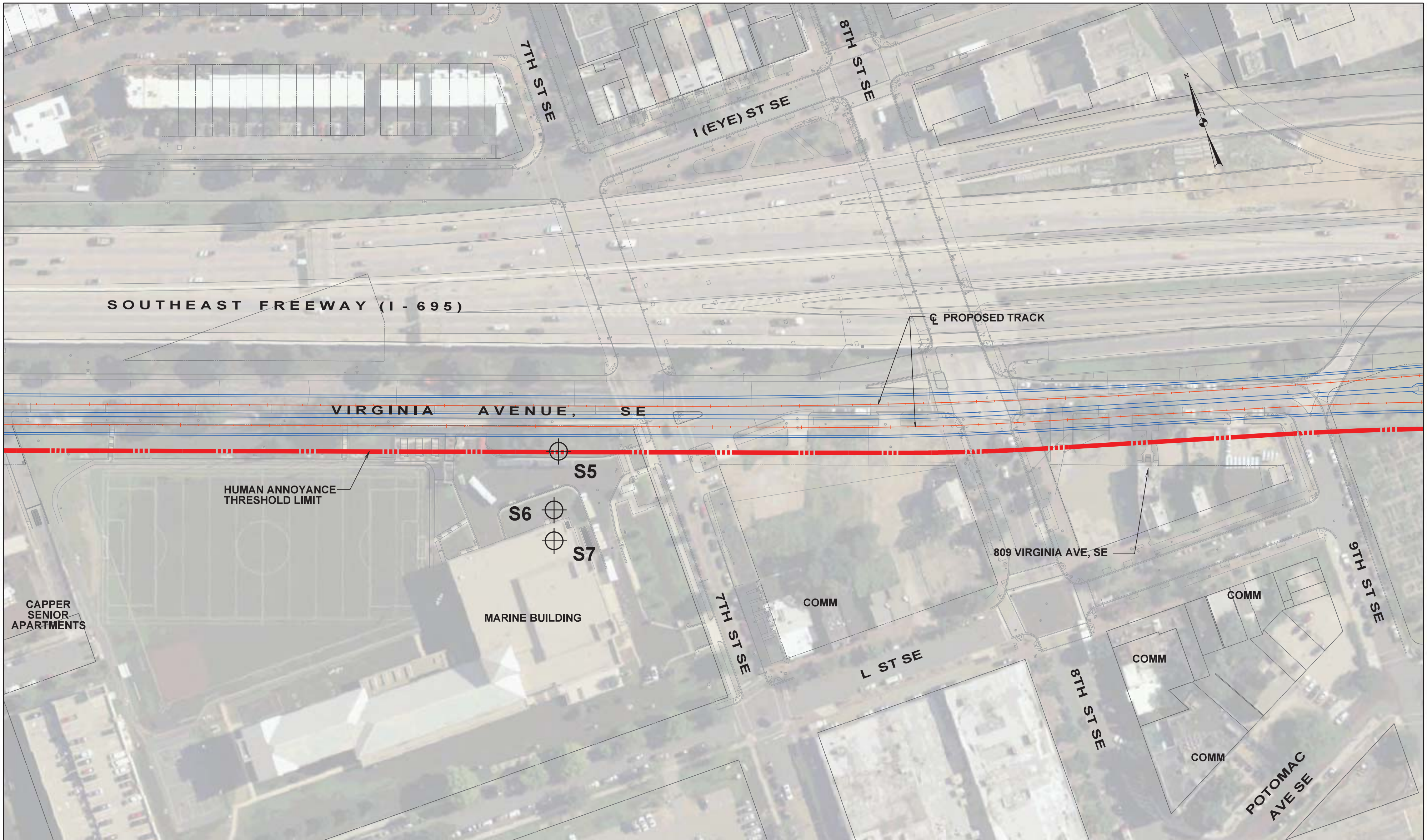

LEGEND

⌖	VIBRATION MEASUREMENT SITE
S12	VIBRATION MEASUREMENT SITE NUMBER
(red line)	HUMAN ANNOYANCE IMPACT LINE
COMM	COMMERCIAL
(orange line)	℄ PROPOSED TRACK
(blue line)	PROPOSED TUNNEL WALL

CLARK CONSTRUCTION
PARSONS
100 M Street SE, Washington, DC 20003

VIRGINIA AVENUE TUNNEL

VIBRATION MEASUREMENT SITES - ALTERNATIVE 3

FIGURE 3

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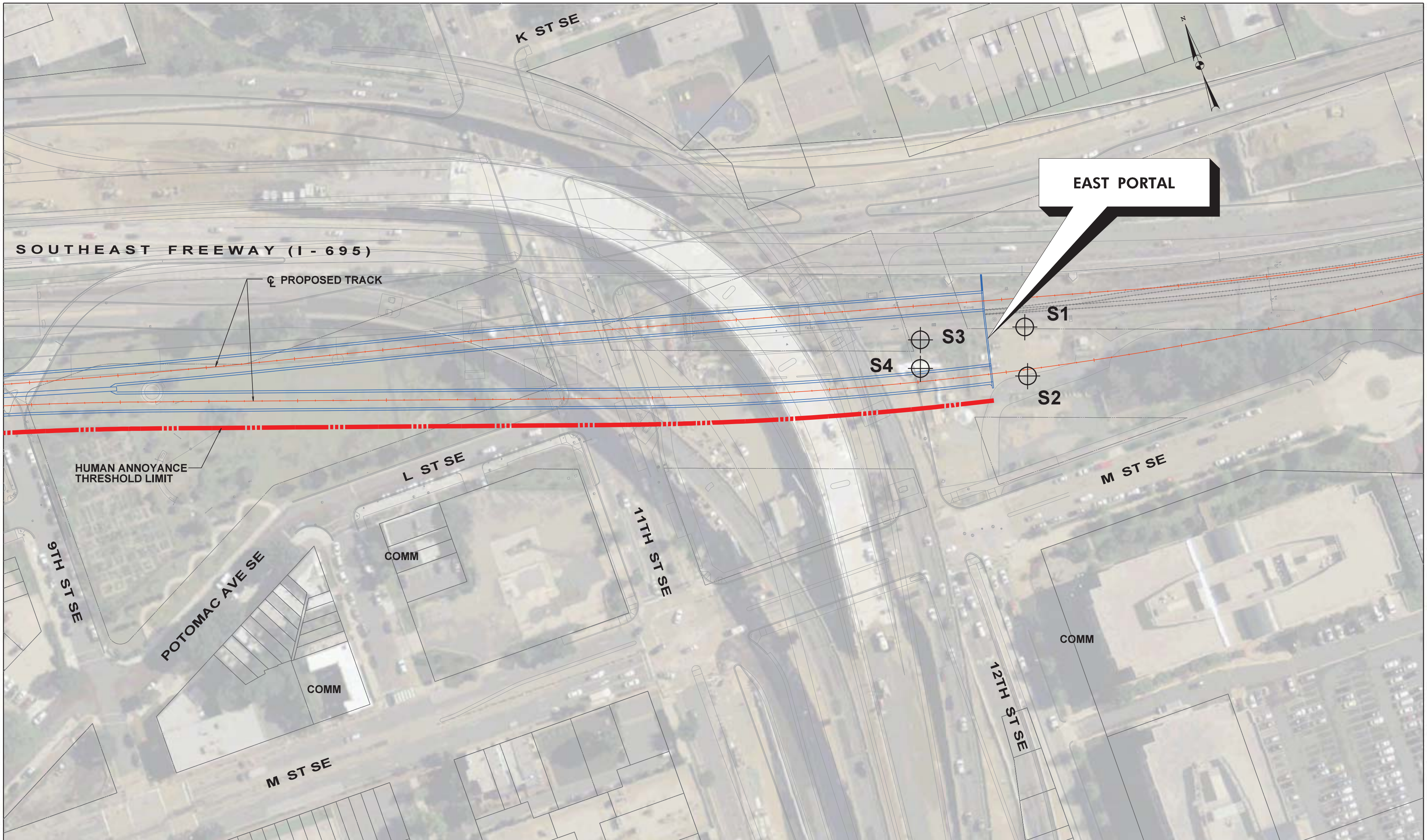

LEGEND

⌖	VIBRATION MEASUREMENT SITE	COMM	COMMERCIAL
S12	VIBRATION MEASUREMENT SITE NUMBER	(red line)	℄ PROPOSED TRACK
(red dashed line)	HUMAN ANNOYANCE IMPACT LINE	(blue lines)	PROPOSED TUNNEL WALL

CLARK CONSTRUCTION
PARSONS
100 M Street SE, Washington, DC 20003

VIRGINIA AVENUE TUNNEL

VIBRATION MEASUREMENT SITES - ALTERNATIVE 3

FIGURE 4

34972
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B SOIL VIBRATION TRANSFERABILITY AND REDUCTION DATA

Table B-1. Soil Vibration Transferability Characteristic Calculations

Measurement Date	Peak Measurements: Sites 1 and 3 (Near) Vert RMS VdB[1]	Sites 1 and 3 (Near) Vert PPV (in/sec)	Sites 2 and 4 (Far) Vert. RMS VdB[1]	Sites 2 and 4 (Far) Vert. PPV (in/sec)	Soil Factor
5/23/2012	85	0.070	82	0.048	**0.28**
5/23/2012	86	0.083	82	0.050	**0.37**
5/23/2012	82	0.050	78	0.030	**0.38**
5/23/2012	87	0.088	82	0.050	**0.42**
5/23/2012	82	0.053	78	0.030	**0.42**
5/23/2012	82	0.050	77	0.028	**0.43**
5/23/2012	82	0.050	77	0.028	**0.43**
5/23/2012	83	0.055	78	0.030	**0.45**
5/23/2012	86	0.080	81	0.043	**0.46**
5/23/2012	81	0.043	75	0.023	**0.46**
5/23/2012	82	0.048	76	0.025	**0.48**
5/23/2012	84	0.060	78	0.030	**0.51**
5/23/2012	85	0.070	79	0.035	**0.51**
5/23/2012	82	0.048	75	0.023	**0.54**
5/23/2012	84	0.063	78	0.030	**0.55**
5/23/2012	84	0.065	78	0.030	**0.57**
5/23/2012	84	0.065	78	0.030	**0.57**
5/23/2012	82	0.050	75	0.023	**0.57**
5/23/2012	83	0.055	76	0.025	**0.58**
5/23/2012	84	0.063	77	0.028	**0.60**
5/23/2012	84	0.065	77	0.028	**0.62**
5/23/2012	79	0.035	71	0.015	**0.62**
5/23/2012	85	0.068	77	0.028	**0.65**
5/23/2012	83	0.058	75	0.023	**0.68**
5/23/2012	83	0.058	75	0.023	**0.68**
12/19/2013	80	0.040	78	0.033	**0.25**
12/19/2013	80	0.040	78	0.033	**0.25**
12/19/2013	77	0.028	75	0.023	**0.26**
12/19/2013	77	0.028	75	0.023	**0.26**
12/19/2013	81	0.043	79	0.035	**0.27**
12/19/2013	76	0.025	74	0.020	**0.29**
12/19/2013	79	0.035	77	0.028	**0.29**
12/19/2013	79	0.035	77	0.028	**0.29**
12/19/2013	76	0.025	74	0.020	**0.29**
12/19/2013	79	0.035	77	0.028	**0.29**
12/19/2013	81	0.045	79	0.035	**0.33**
12/19/2013	81	0.045	79	0.035	**0.33**
12/19/2013	78	0.030	75	0.023	**0.35**
12/19/2013	78	0.030	75	0.023	**0.35**
12/19/2013	78	0.030	75	0.023	**0.35**
12/19/2013	78	0.030	75	0.023	**0.35**
12/19/2013	78	0.033	76	0.025	**0.36**
12/19/2013	78	0.033	76	0.025	**0.36**
12/19/2013	74	0.020	71	0.015	**0.38**
12/19/2013	80	0.040	78	0.030	**0.38**
12/19/2013	80	0.040	78	0.030	**0.38**
12/19/2013	80	0.040	78	0.030	**0.38**
12/19/2013	80	0.040	78	0.030	**0.38**
12/19/2013	80	0.040	78	0.030	**0.38**
12/19/2013	80	0.038	77	0.028	**0.40**
12/19/2013	73	0.018	70	0.013	**0.43**
12/19/2013	76	0.025	73	0.018	**0.43**
12/19/2013	76	0.025	73	0.018	**0.43**
12/19/2013	79	0.035	76	0.025	**0.44**
12/19/2013	77	0.028	74	0.020	**0.44**

Measurement Date	Peak Measurements: Sites 3 (Near) Vert RMS VdB[1]	Sites 3 (Near) Vert PPV (in/sec)	Sites 4 (Far) Vert. RMS VdB[1]	Sites 4 (Far) Vert. PPV (in/sec)	Soil Factor
12/19/2013	77	0.028	74	0.020	**0.44**
12/19/2013	77	0.028	74	0.020	**0.44**
12/19/2013	79	0.035	76	0.025	**0.44**
12/19/2013	80	0.040	77	0.028	**0.47**
12/19/2013	80	0.040	77	0.028	**0.47**
12/19/2013	80	0.040	77	0.028	**0.47**
12/19/2013	80	0.040	77	0.028	**0.47**
12/19/2013	80	0.040	77	0.028	**0.47**
12/19/2013	81	0.043	78	0.030	**0.47**
12/19/2013	81	0.043	78	0.030	**0.47**
12/19/2013	81	0.043	78	0.030	**0.47**
12/19/2013	81	0.043	78	0.030	**0.47**
12/19/2013	81	0.043	78	0.030	**0.47**
12/19/2013	78	0.033	75	0.023	**0.47**
12/19/2013	78	0.033	75	0.023	**0.47**
12/19/2013	78	0.033	75	0.023	**0.47**
12/19/2013	78	0.033	75	0.023	**0.47**
12/19/2013	78	0.033	75	0.023	**0.47**
12/19/2013	71	0.015	68	0.010	**0.53**
12/19/2013	78	0.030	74	0.020	**0.53**
12/19/2013	81	0.045	78	0.030	**0.53**
12/19/2013	81	0.045	78	0.030	**0.53**
12/19/2013	81	0.045	78	0.030	**0.53**
12/19/2013	82	0.053	79	0.035	**0.54**
12/19/2013	82	0.050	78	0.033	**0.55**
12/19/2013	80	0.038	76	0.025	**0.55**
12/19/2013	80	0.038	76	0.025	**0.55**
12/19/2013	80	0.038	76	0.025	**0.55**
12/19/2013	80	0.038	76	0.025	**0.55**
12/19/2013	75	0.023	71	0.015	**0.56**
12/19/2013	75	0.023	71	0.015	**0.56**
12/19/2013	75	0.023	71	0.015	**0.56**
12/19/2013	81	0.043	77	0.028	**0.56**
12/19/2013	77	0.028	73	0.018	**0.58**
12/19/2013	77	0.028	73	0.018	**0.58**
12/19/2013	83	0.055	79	0.035	**0.59**
12/19/2013	84	0.063	80	0.040	**0.60**
12/19/2013	82	0.048	78	0.030	**0.62**
12/19/2013	66	0.008	62	0.005	**0.62**
12/19/2013	82	0.048	78	0.030	**0.62**
12/19/2013	82	0.053	78	0.033	**0.62**
12/19/2013	81	0.045	77	0.028	**0.62**
12/19/2013	81	0.045	77	0.028	**0.62**
12/19/2013	81	0.045	77	0.028	**0.62**
12/19/2013	70	0.013	66	0.008	**0.64**
12/19/2013	80	0.038	75	0.023	**0.66**
12/19/2013	80	0.038	75	0.023	**0.66**
12/19/2013	84	0.063	80	0.038	**0.66**
12/19/2013	76	0.025	71	0.015	**0.67**
12/19/2013	78	0.030	73	0.018	**0.67**
12/19/2013	78	0.030	73	0.018	**0.67**
12/19/2013	82	0.050	78	0.030	**0.67**
				Average	**0.48**

Note:

1 - Levels in VdB (re: 10-6 in/sec.)

Soil Factor Calculations

$PPV_2 = PPV_1 \times (D1/D2)^a$

Where: PPV_1 = Vibration at point 1, in/sec

PPV_2 = Vibration at point 2, in/sec

D1 = Distance from source to point 1, ft

D2 = Distance from source to point 2, ft

a = Soil transfer factor

Table B-2. Vibration Reduction Adjustment Factor due to the Existing Tunnel May 2012

Vibration Source	Time	Marine Band Practice Hall						Capitol Quarter Townhomes					
		Site 5 61 ft from center of track			Site 6 127 ft from center of track			Site 11 40 ft from center of track			Site 12 73 ft from center of track		
		PPV, (in/sec)			PPV, (in/sec)			PPV, (in/sec)			PPV, (in/sec)		
		With Tunnel	Without Tunnel	Reduction due to Tunnel	With Tunnel	Without Tunnel	Reduction due to Tunnel	With Tunnel	Without Tunnel	Reduction due to Tunnel	With Tunnel	Without Tunnel	Reduction due to Tunnel
Train with 120 Cars traveling at 19 mph	11:45:00	0.013	0.054	**0.041**	0.005	0.041	**0.036**	0.013	0.063	**0.050**	0.01	0.050	**0.040**
	11:45:30	0.005	0.027	**0.022**	0.005	0.019	**0.014**	0.005	0.034	**0.029**	0.01	0.025	**0.015**
	11:46:00	0.005	0.025	**0.020**	0.005	0.018	**0.013**	0.008	0.031	**0.023**	0.008	0.023	**0.015**
	11:46:30	0.008	0.026	**0.018**	0.005	0.017	**0.012**	0.008	0.032	**0.024**	0.008	0.023	**0.015**
	11:47:00	0.005	0.033	**0.028**	0.005	0.022	**0.017**	0.008	0.043	**0.035**	0.008	0.030	**0.022**
	11:47:30	0.005	0.026	**0.021**	0.005	0.017	**0.012**	0.005	0.033	**0.028**	0.008	0.023	**0.015**
	11:48:00	0.008	0.032	**0.024**	0.005	0.020	**0.015**	0.008	0.042	**0.034**	0.008	0.028	**0.020**
	11:48:30	0.005	0.033	**0.028**	0.005	0.024	**0.019**	0.008	0.039	**0.031**	0.008	0.030	**0.022**
Train with 70 Cars traveling at 12 mph	12:40:00	0.005	0.033	**0.028**	0.005	0.022	**0.017**	0.013	0.043	**0.030**	0.01	0.030	**0.020**
	12:40:30	0.01	0.030	**0.020**	0.005	0.022	**0.017**	0.015	0.036	**0.021**	0.013	0.028	**0.015**
	12:41:00	0.01	0.026	**0.016**	0.008	0.016	**0.008**	0.013	0.035	**0.022**	0.01	0.023	**0.013**
	12:41:30	0.008	0.032	**0.024**	0.005	0.019	**0.014**	0.013	0.044	**0.031**	0.01	0.028	**0.018**
	12:42:00	0.01	0.026	**0.016**	0.005	0.016	**0.011**	0.005	0.035	**0.030**	0.008	0.023	**0.015**
Train with 143 Cars traveling at 14 mph	13:47:30	0.008	0.051	**0.043**	0.005	0.041	**0.036**	0.005	0.057	**0.052**	0.008	0.048	**0.040**
	13:48:00	0.01	0.033	**0.023**	0.005	0.022	**0.017**	0.005	0.042	**0.037**	0.008	0.030	**0.022**
	13:48:30	0.005	0.032	**0.027**	0.005	0.020	**0.015**	0.005	0.041	**0.036**	0.008	0.028	**0.020**
	13:49:00	0.005	0.031	**0.026**	0.005	0.020	**0.015**	0.005	0.040	**0.035**	0.008	0.028	**0.020**
	13:50:00	0.008	0.029	**0.021**	0.005	0.017	**0.012**	0.005	0.039	**0.034**	0.008	0.025	**0.017**
	13:50:30	0.008	0.030	**0.022**	0.005	0.022	**0.017**	0.005	0.036	**0.031**	0.008	0.028	**0.020**
	13:51:00	0.005	0.033	**0.028**	0.005	0.023	**0.018**	0.005	0.041	**0.036**	0.008	0.030	**0.022**
	13:51:30	0.008	0.033	**0.025**	0.005	0.024	**0.019**	0.01	0.039	**0.029**	0.008	0.030	**0.022**
	13:52:00	0.01	0.028	**0.018**	0.005	0.018	**0.013**	0.005	0.036	**0.031**	0.01	0.025	**0.015**
Train with 47 Cars traveling at 20 mph	14:00:30	0.013	0.054	**0.041**	0.008	0.040	**0.032**	0.01	0.065	**0.055**	0.01	0.050	**0.040**
	14:01:30	0.008	0.032	**0.024**	0.005	0.024	**0.019**	0.005	0.038	**0.033**	0.008	0.030	**0.022**
	14:02:00	0.01	0.039	**0.029**	0.005	0.027	**0.022**	0.005	0.048	**0.043**	0.008	0.035	**0.027**
	14:02:30	0.008	0.017	**0.009**	0.005	0.011	**0.006**	0.005	0.022	**0.017**	0.008	0.015	**0.007**
Train with 28 Cars traveling at 20 mph	14:16:00	0.015	0.047	**0.032**	0.005	0.034	**0.029**	0.013	0.057	**0.044**	0.013	0.043	**0.030**
Average		0.008	0.033	**0.025**	0.005	0.023	**0.018**	0.008	0.041	**0.033**	0.009	0.030	**0.021**

Table B-3. Vibration Reduction Adjustment Factor due to the Existing Tunnel December 2013

Vibration Source	Time	Capper Senior Apartments						St. Paul African Union Methodist Protestant Church		
		Site 8 25 ft from center of track			Site 9 68 ft from center of track			Site 10 179 ft from center of track		
		PPV, (in/sec)			PPV, (in/sec)			PPV, (in/sec)		
		With Tunnel	Without Tunnel	Reduction due to Tunnel	With Tunnel	Without Tunnel	Reduction due to Tunnel	With Tunnel	Without Tunnel	Reduction due to Tunnel
12:35 Train with 69 Cars traveling at 19 mph	12:35:00	0.035	0.068	**0.033**	0.013	0.033	**0.020**	0.008	0.016	**0.008**
12:58 Train with 42 Cars traveling at 14 mph	12:58:00	0.018	0.049	**0.031**	0.008	0.025	**0.017**	0.008	0.015	**0.007**
	12:59:00	0.028	0.041	**0.013**	0.01	0.020	**0.010**	0.008	0.010	**0.002**
13:14 Train with 66 Cars traveling at 12 mph	13:14:00	0.015	0.042	**0.027**	0.008	0.025	**0.017**	0.005	0.015	**0.010**
13:40 Train with 86 Cars traveling at 19 mph	13:42:00	0.013	0.052	**0.039**	0.008	0.026	**0.018**	0.005	0.014	**0.009**
	13:43:00	0.013	0.047	**0.034**	0.008	0.033	**0.025**	0.005	0.023	**0.018**
13:46 Train with 64 Cars traveling at 18 mph	13:46:00	0.018	0.042	**0.024**	0.010	0.025	**0.015**	0.010	0.015	**0.005**
	13:47:00	0.025	0.042	**0.017**	0.010	0.028	**0.018**	0.013	0.019	**0.006**
	13:48:00	0.023	0.041	**0.018**	0.010	0.022	**0.012**	0.003	0.012	**0.009**
Average		0.021	0.047	**0.026**	0.009	0.027	**0.017**	0.007	0.015	**0.008**

Average tunnel reduction calculated using May 2012 and Dec 2013 data 0.021 in/sec

C CONSTRUCTION ACTIVITIY

Table C-1. Construction Activities Assumptions for Vibration Estimates

CONSTRUCTION ACTIVITY [1]	ANTICIPATED EQUIPMENT	MINIMUM DISTANCE TO CONSTRUCTION ACTIVITY (FT)					
		809 VIRGINIA AVENUE	MARINE BAND PRACTICE HALL	CAPPER SENIOR APARTMENTS	ST. PAUL AFRICAN UNION METHODIST PROTESTANT CHURCH	CAPITAL QUARTER TOWNHOUSES	200 I STREET
Utility Relocation	• Small Back Hoe [2] • Utility Truck	38	88	25	128	23	23
Surface Demolition	• Jack Hammer [2] • Front End Loader • Dump Truck	50	100	18	18	25	38
Existing Tunnel Demolition	• Back Hoe (Cat 325 or equivalent) • Track Loader (Cat 973 or equivalent) • Hoe Ram [2] • Dump Truck	70	120	60	160	56	55
Support of Excavation	• Drill Rig (Soilmec 622) [2] • Forklift (10000 lb) • Welding Machine	43	93	30	133	28	28
Excavation	• Back Hoe (Cat 325 or equivalent) • Track Loader (Cat 973 or equivalent) [2] • Dump Truck	44	94	31	134	29	29
Tunnel Structure Construction	• Truck Mixer • Crane (60 Ton Rubber Tire) [2] • Tractor Trailer • Forklift (10000 lb) • Air Compressor	45	95	32	135	30	30
Backfill	• Roller/Compactor • Light Plant • Motor Grader • Dozer (Cat D7 or equivalent) [2]	44	94	31	134	29	29
Roadway Construction	• Non-vibratory Roller • Paver • Dump Truck • Light Plant • Motor Grader • Dozer (Cat D7 or equivalent) [2]	55	110	30	135	50	40
Sheet Pile (Alt 4 Only) [3]	• Vibratory Pile Driver [2] • 100 Ton Crawler Crane • Crane (60 Ton Rubber Tire) • Welding Machine	68	118	58	158	54	53

Notes:

[1] Construction activities were predicted using the best information available at the time the study was prepared.

[2] Indicates the highest vibration producing construction equipment that was used to predict vibration levels for the construction activity.

[3] Indicates that the construction activity will only take place for Alternative 4.

CLARK/PARSONS, JOINT VENTURE
100 M Street SE, Suite 1200
Washington, DC 20003
Phone: 202-775-3300 • Fax: 202-775-3420

Attachment 2

Councilmember Allen Letter to DDOT

COUNCIL OF THE DISTRICT OF COLUMBIA
THE JOHN A. WILSON BUILDING
1350 PENNSYLVANIA AVENUE, NW
WASHINGTON, DC 20004

Charles Allen
Councilmember, Ward 6
Chairperson
Committee on the Judiciary and Public Safety

Committee Member
Business and Economic Development
Education
Transportation and the Environment

May 10, 2017

Leif Dormsjo, Director
District Department of Transportation
55 M Street, SE
Washington, DC 20003

Dear Director Dormsjo:

I have heard from many Ward 6 residents residing along the 400 block of Virginia Avenue, SE, regarding concerns about damage to their homes possibly due to vibrations from the new double-stacked trains that have started to utilize the upgraded Virginia Avenue Tunnel.

I would respectfully request your agency review, investigate, and evaluate any vibrations in the public space along the 300, 400, and 500 blocks of Virginia Avenue, SE and its potential impact on private property. Please advise if DDOT finds that CSX has taken the appropriate steps mandated by the Final Environmental Impact Statement for the VAT Project to insulate the public space and private homes from the effects of construction activities and the increase in train size.

I appreciate your consideration of this request and any recommendations DDOT can share with regard to additional steps that may mitigate project- and train-related vibrations in the residential area adjacent to the tunnel.

Sincerely,

Councilmember Charles Allen, Ward 6
Chair, Committee on the Judiciary and Public Safety

cc: Councilmember Mary Cheh, Ward 3, Chair, Committee on Transportation and the Environment
ANC6D Commissioner Meredith Fascett

Attachment 3

DDOT Response Letter to Councilmember Allen

Government of the District of Columbia

Department of Transportation

d. Office of the Director

May 23, 2017

Hon. Charles Allen
Councilmember, Ward 6
Council of the District of Columbia
1350 Pennsylvania Avenue, NW
Suite 110
Washington, DC 20004

Re: Virginia Avenue Tunnel Vibration Monitoring Analysis

Dear Councilmember Allen:

Thank you for your May 15, 2017 letter regarding noise and vibration concerns around the Virginia Avenue Tunnel. DDOT is aware of the concerns raised by residents in the Capitol Quarter community about increased vibration since CSX began running trains in the new Phase 1 tunnel in December 2016. DDOT is working with CSX to determine the causes and to develop mitigation plans.

As a requirement of the Final Environmental Impact Statement (FEIS) for the Virginia Avenue Tunnel Project, CSX established a vibration monitoring program that has been in place since construction began. The program includes eight vibration monitoring devices spread out along the construction site. One of the monitors is directly in front of the rowhomes in the 300 block of Virginia Avenue.

CSX installed the monitoring system in April 2015 to establish pre-construction vibration levels, and has been providing continuous monitoring throughout construction. CSX and their contractor are notified in real-time when vibration levels exceed established thresholds, and normally stop work until they have identified and addressed the source of the vibration. CSX reports bi-weekly to DDOT of any vibration levels that exceed the thresholds and prepares monthly summary reports on the vibration levels. These reports are available to the public at http://www.virginiaavenuetunnel.com/environmental-reports and are reviewed by DDOT to ensure CSX remains in compliance with the terms of the FEIS. Since construction began, CSX has reported 16 exceedances of vibration criteria across the eight monitoring stations. CSX has not reported an increase in the number of exceedances since trains began running in the new tunnel.

In response to the community concerns, DDOT has secured the services of a vibration analyst to review the CSX data and recommend improvements to the reporting. We anticipate the report from the vibration analyst to be available in approximately 30 days. DDOT has also reviewed the format and content of the vibration reports, and has provided specific comments to CSX on ways to improve the reports to ensure they provide information that will be usable by the community.

DDOT is working with the lead Federal agency, the Federal Highway Administration, to review the vibration analysis and potentially identify additional investigation needed. If the increased vibration is found to be caused by CSX rail operations, DDOT will work with all parties to identify any additional mitigation measures required.

If you have any questions on this matter, please do not hesitate to contact me or Ravindra Ganvir, Deputy Chief Engineer for Anacostia Waterfront Initiative projects at (202) 671-4689 or ravindra.ganvir@dc.gov. DDOT will continue to work with the residents and with CSX to ensure that this matter is addressed.

Sincerely,

Jeffrey M. Marootian
Deputy Director

Cc: Christopher Lawson, FHWA

Attachment 4

Email Comments from Meredith Fascett with Responses

RESPONSE TO 5/12/17 EMAIL FROM MEREDITH FASCETT

Data Collection

Was the expert given access to the full vibrations data set?

> *DDOT did request the full vibrations data set. CSX and their monitoring team have participated in numerous discussions with the DDOT vibration analysts where CSX shared relevant excerpts of the vibration data and analysis. The vibration data consisted of the construction monitoring summaries, previous studies conducted during the environmental review process, time series plots of vibration levels, and summary results of the supplemental train pass-by vibration data. The full vibration data set is too large, and could not be reviewed by DDOT. However, the available data do not allow a correlation of resident vibration observations to project and non-project activities.*

In the expert's judgment, are the CSX vibration monitors placed in the proper positions to monitor vibrations in all of the front row residences?

> *The construction vibration monitors are placed appropriately to meet the commitments made in the EIS. There are three construction monitors in proximity to front row residences that provide data to monitor construction activities and allow CSX to stop work when building damage thresholds are approached. The supplemental operational monitoring required additional sensors, which were placed in the tunnel and at the CSX townhouse. This is the closest structure to the new tunnel, and should be subject to the highest vibration levels.*

Incident Assessments

I need a full understanding of the incidents of vibrations over the course of the project thus far. Accordingly, please provide details, e.g. dates, frequency, measurements, and duration of all vibration incidents that would be noticeable to residents. Please also provide extensive details, including the likely cause, e.g. construction, train transit or other, on any vibration incidents that approached or exceeded the allowable levels. In the case of vibrations caused by train transit, please include the travel speed of the train.

> *DDOT does not have access to the full vibration data set for construction monitoring or supplemental operations monitoring. Even with the full data set, it is not feasible to extract each vibration incidence that would be perceptible.*
>
> *The construction monitoring program is intended to provide warnings to CSX when vibration from construction activities approaches the structural damage threshold so they can adjust construction means and methods to reduce impacts. The CSX monitoring team noted that they receive data in real-time and review all approach and exceedance notifications to determine if the cause is construction-related or caused by other factors. All construction-related exceedances are reported in the monthly report.*
>
> *The construction monitoring program is not intended to provide detailed information on each vibration incidence that could be noticeable to residents. The supplemental monitoring program carried out by CSX in early June provided additional data on vibration propagation from train pass-by events to compare to the thresholds identified for human annoyance. DDOT requested that the supplemental vibration report also include a review that cross-references the vibration data to other potential vibration causes and CSX train schedules, but CSX determined that it was not feasible to provide this information.*
>
> *Pre-project monitoring conducted to support the environmental review process noted:*

> Numerous vibration events were recorded when there were no train operations in the tunnel. Many of these events produced vibration levels that were of equal or greater magnitude than vibration levels generated from train operations. It was beyond the scope of this study to determine the specific nature of the events causing these vibrations. However, neither the frequency nor the magnitudes of these "non-train" vibrations are unusual in an urban environment. (Page ES-4)

Note: If the information on the timing and speed of the trains transiting the tunnel has not already been made available to DDOT, please require it. If the data has not been recorded, please require the immediate installation of sensors within the two tunnels.

CSX reported that the maximum speed of trains through the tunnel is 25 mph. DDOT requested that CSX include train speed with the supplemental vibration summary data, but the sensors used did not collect operating speed. DDOT was able to use the train length and passage time to calculate speed, which resulted in estimated speeds of less than 25 mph.

Also, please note that residents disagree with CSX's assertion that the vibration incidents are caused by trucks on the highway or the Metro green line. The vibration incidents typically last far too long to be trucks on the highway, are at hours when Metro isn't operational, and/or are sometimes accompanied by train horns. Accordingly, please address this assertion by CSX.

DDOT agrees that traffic on I-695 or Metro Green Line trains are not likely to cause vibration in excess of the identified limits at the houses on Virginia Avenue. However, DDOT is also aware that pre-project monitoring identified periodic vibration events when there was no train activity.

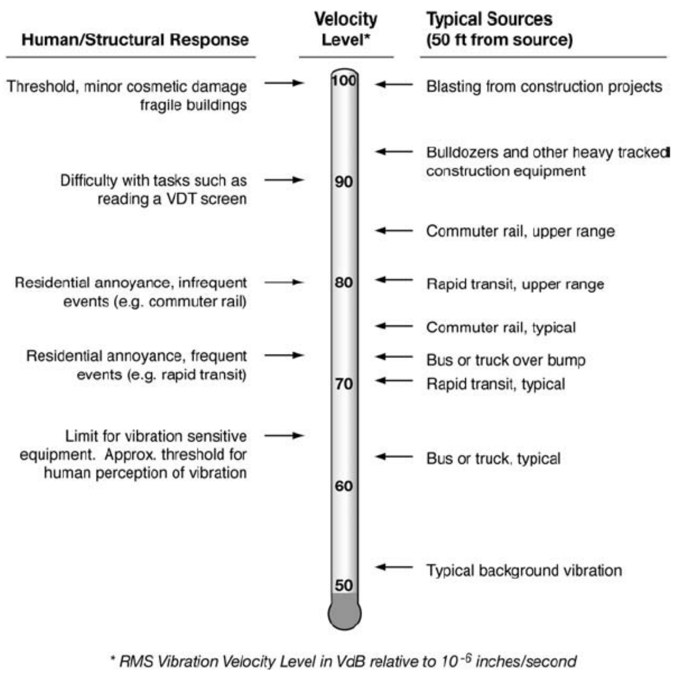
Reevaluation of Assumptions

As you know, once CSX started running trains through the new tunnel, residents began to experience vibrations from the train transit. Numerous residents have reported that their homes shake, they are awakened in the middle of the night by vibrations, etc. Based on these incidents, it is clear that the EIS was incorrect in determining that residents would not experience vibrations from train transit during construction.

Please ask the expert to identify the faulty assumptions that led to the incorrect determination. Please also ask the expert if the same faulty assumptions were used in the EIS's determination that residents would not experience vibrations upon the completion of the tunnel.

The EIS predicted that vibrations from train operations would increase after completion of the new tunnels, but also noted that the future levels were not expected to exceed 80 VdB in the front row residences in the 300, 400 and 500 blocks of Virginia Avenue. The EIS also documented that the area was subject to periodic sources of non-rail vibrations. The CSX supplemental vibration monitoring program indicated that vibrations from rail operations do not exceed the 80 VdB criteria, and are generally less than 70 VdB. At this point, there is no basis to revise the analysis completed in the EIS.

No federal or state regulatory limits for vibration have been identified. The construction and operational vibration guidance established by FTA (2006) are an indicative threshold that have been referred to by other jurisdictions when no clear applicable regulation has been identified. The FTA guidelines for assessing the impacts of ground-borne vibration associated with construction note that the primary vibration concern during construction is potential damage of nearby structures. The FTA indicative criteria for architectural damage to non-engineered timber and masonry buildings is a peak particle velocity of 0.2 in/sec which correlates to a vibration level of approximately 94 VdB. For vibrations associated with rail operations, the FTA guidance depends on the nature of the receiving land use and the number of events per day. The rail operations criteria are based on FTA human *annoyance guidelines. In the case of the front row residences, the EIS referenced the vibration level of 80 VdB. The chart below identifies typical environmental vibration levels.*



<u>Revised Impact Assessment</u>

Based on the data collected thus far (not from the faulty EIS assumptions), what range of vibration levels should be expected when CSX begins running trains through the tunnel at 40 mph? What range of vibrations should be expected when CSX begins running trains simultaneously through both tunnels? What is the likely average and maximum vibration incident when trains are transiting the tunnels? What is the projected duration of the vibrations – 2-3 minutes? 10 minutes?

To what extent are we subject to additional vibrations because the trains are now about 25 feet closer to homes?

To what extent are we subject to additional vibrations because the tunnel walls are thinner?

To what extent are we subject to additional vibrations because of increased train speeds?

To what extent are we subject to additional vibrations because of increased train weights?

Trains are currently operating at 25 mph in the tunnel. CSX has stated that operational considerations will dictate train speeds in the future. According to planning level computations provided by FTA, an increase in speed from 25 mph to 40 mph would lead to an increase of 4 VdB. The CSX Vibration Analysis Report predicted vibration levels of 78 VdB after tunnel completion. This predicted value was based on 40 mph speed and a train in each tunnel simultaneously.

The CSX supplemental vibration monitoring program indicated that vibrations from rail operations are not exceeding the 80 VdB criteria, and are generally less than 70 VdB. At this point, there is no basis to revise the analysis completed in the EIS.

What vibration levels, at what frequency, for what duration can the front row residences withstand before they incur damages? To what extent might homes be damaged by increases in the frequency of vibration-causing trains? What is the likely average vibration impact when trains transit the tunnel? How frequently can the front row residences experience that level of sustained vibrations before they are damaged? Is there a cumulative impact to the structure? What metrics are you using determine the ability of the homes to withstand vibrations?

As noted in the EIS, the vibration level where structural damage becomes a concern is a Peak Particle Velocity (PPV) of 0.2 inches per second (approximately 94 VdB). The FTA Guidance is provided in Table 12-3 (copied below) and FTA notes that "These limits should be viewed as criteria that should be used during the environmental impact assessment phase to identify problem locations that must be addressed during final design."

Table 12-3. Construction Vibration Damage Criteria[11]

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

† RMS velocity in decibels (VdB) re 1 micro-inch/second

This level has been exceeded in discrete instances due to construction activities, but there is no indication that it has been exceeded due to rail operations. The data available to date do not indicate any concern about building damage due to train operations. CSX has established a claims process for homeowners who believe that their property has been damaged by construction vibrations.

Please assess the impact of vibrations on the freeway, both now and after that second new tunnel becomes operational. CSX said that the freeway would be fine, and that residents would not be able to hear or feel the train vibrations. The latter is not true. Perhaps the former isn't, either.

CSX is providing continuous monitoring of the freeway structure for both settlement and movement. The freeway bridges and retaining walls are constructed on deep foundations and built to handle substantial loads. DDOT engineers are not concerned about rail vibrations causing damage.

<u>Mitigation</u>

What mitigations can CSX make to the tunnel(s) themselves to decrease vibrations?

CSX has made modifications to the track in the tunnel that may reduce vibration levels. These measures include increasing the depth of ballast, installing friction modifiers on the rail, and track resurfacing. As the precise nature or source of the vibrations has not been clearly established, CSX is uncertain if these additional measures will be effective.

There are a variety of mitigation technologies available to address specific types of rail vibration, but their implementation must be engineered to the specific vibration characteristics of this project. Consideration for reducing train vibration at the source (e.g. wheel flats), through the track (e.g. top-of-rail modifiers), through the track/ballast system (e.g. rail pads), and through the tunnel structure and ground requires a system approach to ensure the specific vibration characteristics at the building are addressed.

In the absence of an engineering solution, what is the maximum speed that trains can transit the tunnel without 1) creating noticeable vibrations and 2) exceeding the allowable vibration levels?

Trains are currently operating at 25 mph on the approach tracks and in the tunnel. As a planning-level rule of thumb, FTA suggests that increasing or decreasing the train speed by a factor of two is expected to lead to a 6 VdB increase or decrease in vibration levels. The speed of a train is only one factor, and cannot be separated out from other factors.

Other - Questions for DDOT

Can DDOT ask -- or, better yet require -- CSX to provide real-time environmental monitoring (or, at least, vibration monitoring) results to the public? Yes, the FEIS/ROD does not require this. Then again, those documents also said that we wouldn't be able to feel vibrations from the trains. We need more than these long-after-the-fact, artfully-worded summaries. Alternately, can DDOT do its own vibration monitoring? If CSX won't provide real-time monitoring, perhaps DDOT could.

DDOT will ask CSX to make the real-time data available to the public. At this time, DDOT does not intend to perform additional monitoring and will continue to work with CSX to correlate the monitored data with project and non-project activities.

Is the DC government monitoring train speeds and frequency? If so, can it share that information? If not, can it please start?

DDOT does not have a system installed to monitor CSX operations and is expecting that CSX will start to correlate the measured data with their operations.

Can the DC government provide real-time public monitoring of vibration even after construction, when trains will be running in both directions and when CSX has said that it will increase speed of the trains yet again?

DDOT will coordinate with FHWA to determine if additional monitoring is appropriate after completion of construction.

RESPONSE TO 5/25/17 EMAIL FROM MEREDITH FASCETT (909 4th Street)

I was just awakened by the vibrations in my house right now at 4:16 am. It woke me up last night too, but I was too disoriented to be sure.

This is nuts. I'm not that close to VA Ave. I can only imagine how other houses might be affected.

Please make sure the vibrations expert is answering all the questions and providing really good analysis. We need to get this figured out and fixed.

DDOT discussed this specific incidence with CSX. CSX reported that there was a train passage within the reported time frame. Review of the construction monitoring data from the closest monitoring station (Location 4 in front of the church at 4th and I Street) found the highest measurement within this time period to be 66 VdB.

RESPONSE TO 5/30/17 EMAIL FROM MEREDITH FASCETT

I know we've talked about how since no vibration were expected from train transit, no mitigation was required from the onset of the project. But, given that we are clearly experiencing vibrations from train transit, doesn't the following apply from the ROD?

> **ROD Appendix C:**
>
> "Response to Comment 35-15:
>
> If vibration from trains passing through the new tunnel can be felt (or cause damage) despite the results of the vibration study conducted for this Project, **the project sponsor will be obligated to fix the problem**. Vibration monitoring will be conducted throughout construction, including when trains begin operating within the new south side tunnel."
>
> "Response to Comment 39-15:
>
> If vibration from trains passing through the new tunnel can be felt (or causes damage) despite the results of the vibration study conducted for this Project, **the project sponsor will be obligated to fix the problem.** Vibration monitoring will be conducted throughout construction, including when trains begin operating within the new south side tunnel. As a point of clarification, freight trains pulling doublestack intermodal container cars do not produce any more vibration than other types of train traffic. For example, trains carrying coal are heavier."

FHWA may require CSX to provide mitigation if it is determined that rail operations are causing vibration impacts beyond regulatory requirements.

RESPONSE TO 7/7/17 CONVERSATION BETWEEN RAVINDRA GANVIR AND MEREDITH FASCETT

1. Where are the new vibration monitors located that CSX is installing to get additional data?

   CSX installed three monitors for the supplemental monitoring program:

   - *In the tunnel on the tunnel floor*
   - *On the ground outside the CSX townhouse*
   - *On the garage floor inside the CSX townhouse*

   The configuration of the monitors allowed CSX to determine vibration levels at the track level and propagation of vibration through the tunnel structure and existing ground.

2. People at the higher floors are complaining about more vibrations than people on the bottom floor? What is your expert opinion about the vibrations felt at different elevations? Are there any remedies to provide for people at the higher floor?

   It is possible that vibrations are amplified in higher floors. Any amplification would be dependent on the structural components of the building.

3. Will reducing the train speed reduce vibrations felt by the residents? What is the current operational train speed? What will be the vibrational impact to the residents if the train speed is reduced by 5 mph, 10 mph, 15 mph, 20 mph, 25 mph, 30 mph?

   CSX reports that the current speed of trains running in the tunnel is 25 mph or less. As a planning-level rule of thumb, FTA suggests that increasing or decreasing the train speed by a factor of two is expected to lead to a 6 VdB increase or decrease in vibration levels.

RESPONSE TO 7/25/17 EMAIL FROM DAVID NAFFIS (331 I Street)

Following up on your email from Jun 9 regarding CSX trains and feeling the vibrations in our homes. I did my best to record whenever I felt them. Here are the dates and times. Hopefully it's helpful.

Thursday June 22, 12:10PM
Friday June 23, 3:09PM
Saturday June 24, 7:44AM
Monday June 26, 12:20PM
Monday June 26, 2:08PM
Monday June 26, 5:30PM
Friday June 30, 7:33AM
Monday July 10, 10:51AM
Wednesday July 12, 12:54PM
Saturday July 15, 11:35AM
Saturday July 15, 4:08PM

> *DDOT requested that CSX provide YES/NO response to whether there was a train pass-by at these times, but CSX determined that they would not provide the information.*

Attachment 5

FHWA Letter to CSX

U.S. Department
of Transportation
Federal Highway Administration

District of Columbia Division

1990 K Street, NW
Suite 510
Washington, DC 20006-1103
(202) 219-3570 - Office
(202) 219-3545 - Fax
www.fhwa.dot.gov/dcdiv

May 10, 2017

In Reply Refer To: HFO-DC

William Parry, PG, CGWP
Manager of Environmental Remediation
CSX Transportation, Inc.
One Bell Crossings, Selkirk, NY 12158

Dear Mr. Parry:

The Federal Highway Administration (FHWA) has been informed you are the current Manager of Environmental Remediation for CSX post the retirement of Keith Brinker who was based in CSX's Jacksonville, FL office. FHWA was recently notified of complaints concerning vibration during the reconstruction of the Virginia Avenue Tunnel (VAT) project in Washington, DC. After a review of the various communications involving this issue, it appears the complaints universally involve vibration due to train operations within the tunnel while it is being reconstructed. Until an investigation is undertaken to definitively determine the source of vibration, the referenced complaints serve as anecdotal evidence of an impact that was dismissed on numerous occasions during the environmental phase of the project based on the analysis performed by the CSX consultant team.

FHWA regulatory policy as stated in 23 CFR §771.109 (c)(6) permits a project sponsor, that is a private institution or firm such as CSX, to provide technical studies relevant to its proposed undertaking. In that regard, CSX developed and subsequently provided a technical report, Appendix F – Vibration Analysis Report, that utilized guidance based on procedures outlined in the Federal Transit Administration's (FTA) *Transit Noise and Vibration Impact Assessment* guidelines (FTA 2006) in compliance with FHWA guidance. As stated in the Executive Summary of the technical report (pg. ES-1) "*… FTA guidelines and applicable criteria, vibration impacts were evaluated for human annoyance…*". Therefore, analysis provided in the technical report serves as the basis for discussions on impacts or effects due to vibration in the federally required environmental documentation. Based on analysis in the technical report, the potential for vibration effects or impacts due to trains transiting the tunnel during construction of the VAT was addressed relatively emphatically in numerous instances in the Final EIS as noted by the following statements:

1. Although the outer surface of the southern wall under Alternative 3 will be located approximately 25 feet south of the existing tunnel's outer southern wall, the new enclosed structure, track ballast/bed and concrete floor will serve to prevent proximity effects from train-related vibration to nearby buildings (pg. S-4).

2. Table S-1(pg. S-14)

Vibration				
Construction	None.	Certain construction activities near buildings could cause annoyance to occupants. Train operations during construction not predicted to cause human annoyance or building damage.	Same as the Preferred Alternative.	Same as the Preferred Alternative.
Permanent (Post Construction)	May result in similar vibration impacts noted under construction for Preferred Alternative if tunnel failure occurs.	Train operations not predicted to cause human annoyance or building damage	Same as the Preferred Alternative.	Same as the Preferred Alternative.

Executive Summary S-14

3. **Executive Summary Q & A – Key Issues Raised by Community and Responses** (pg. S-34)
   <u>Question 22:</u> I live along the south side of Virginia Avenue SE, and understand that the new Virginia Avenue Tunnel under the Preferred Alternative will be located closer to my home. Will I hear freight trains passing through the new tunnel? Will I feel the vibration from freight trains passing through the new tunnel?

   <u>Answer</u>: Based on detailed noise and vibration studies conducted for the EIS, the residents will not hear nor be able to feel trains passing through the new tunnel. Sections 5.6 and 5.7 provide further information.

As the basis for determining the relevant factors involved in developing human annoyance criteria with regards to ground-borne vibration due to train operations, CSX developed Table 3-1 (contained in Chapter 3 of <u>Appendix F</u>) which is shown on the following page. Table 3-1 is a derivation of Table 8-1 (also provided) contained in FTA's *<u>Transit Noise and Vibration Impact Assessment</u>* Manual; however, with regards to **<u>applicability to freight trains</u>** (FTA Manual Section 8.1.3) FTA guidance states: "*The impact thresholds given in Tables 8-1 and 8-2 are based on experience with vibration from rail transit systems. They have been used to assess vibration from freight trains since no specific impact criteria exist for freight railroads.* ***However, the significantly greater length, weight and axle loads of freight trains make it problematic to use these impact criteria for freight rail.*** *Nevertheless, in shared right-of-way situations where the proposed transit alignment causes the freight tracks to be moved closer to sensitive sites****, these impact criteria will have to be used****.*" It should be noted that <u>there is no "shared right-of-way" with a rail transit system in this instance</u>. Furthermore, the guidance goes on to state: "…. *However, for a typical line-haul freight train where the rail car vibration lasts for several minutes, the many-event limits should be applied to the rail car vibration.* ***<u>Some judgment must be exercised</u>*** *to make sure that the approach is reasonable…****Finally, it should be pointed out that the vibration control measures developed for rail transit systems are not effective for freight trains****. Consequently, any decision to relocate freight tracks closer to sensitive sites should be made with the understanding that the increased vibration impact due to freight rail will be very difficult, if not impossible, to mitigate*."

Therefore, minus factors involving adjustments made for "judgement" with regards to freight train operations during construction and any subsequent human annoyance due to those trains transiting the

VAT, the criteria provided in Table 8-1 or the derivative Table 3-1 **may not be applicable** in terms of a threshold for impact regarding the VAT project.

Table 3-1. Land Use Categories and Metrics for Rail Vibration Impact Criteria

LAND USE CATEGORY	GROUND-BORNE VIBRATION IMPACT LEVELS PPV AND VdB [5]					
	FREQUENT EVENTS[1]		OCCASIONAL EVENTS[2]		INFREQUENT EVENTS[3]	
Category 1: Buildings where vibration would interfere with interior operations.	0.007 in/sec	65 VdB[4]	0.007 in/sec	65 VdB[4]	0.007 in/sec	65 VdB[4]
Category 2: Residences and buildings where people normally sleep.	0.016 in/sec	72 VdB	0.023 in/sec	75 VdB	0.040 in/sec	80 VdB
Category 3: Institutional land uses with primarily daytime use.	0.023 in/sec	75 VdB	0.032 in/sec	78 VdB	0.056 in/sec	83 VdB

Source: FTA, 2006.

Notes:

1. "Frequent Events" is defined as more than 70 vibration events per day.
2. "Occasional Events" is defined as between 30 and 70 vibration events of the same source per day.
3. "Infrequent Events" is defined as fewer than 30 vibration events per day.
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, such as MRI or electron microscopes, would require detailed evaluation to define acceptable vibration levels.
5. The vibration reference level used to calculate VdB is 1 micro-inch per second.

Table 8-1. Ground-Borne Vibration (GBV) and Ground-Borne Noise (GBN) Impact Criteria for General Assessment

Land Use Category	**GBV Impact Levels (VdB re 1 micro-inch /sec)**			**GBN Impact Levels (dB re 20 micro Pascals)**		
	Frequent Events[1]	**Occasional Events[2]**	**Infrequent Events[3]**	**Frequent Events[1]**	**Occasional Events[2]**	**Infrequent Events[3]**
Category 1: Buildings where vibration would interfere with interior operations.	65 VdB[4]	65 VdB[4]	65 VdB[4]	N/A[4]	N/A[4]	N/A[4]
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

Notes:

1. "Frequent Events" is defined as more than 70 vibration events of the same source 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 source per day. Most commuter 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.

Based on information contained in Technical Report Appendix F, it appears a General Vibration Assessment was performed in lieu of the more rigorous Detailed Vibration Analysis provided in the FTA guidance; however, the technical report's strict use of guidance outlined in the FTA Manual presumably minus adjustments possibly needed for heavy freight make it difficult to dismiss the anecdotal evidence provided in the form of complaints due to perceived vibration from train operations during the VAT reconstruction that are causing human annoyance (see the embedded documents below for informational purposes).

CSX EIS Vibration Issue.msg | CSX Fwd Vibration Issue2.msg | Virginia Avenue Tunnel Vibration Issu | Fwd Vibration Issue.msg | FW Vibration Monitoring.msg

As a result of CSX's analysis and subsequent determinations regarding train operations during the VAT reconstruction, there were no mitigations provided for vibration impacts or effects that cause human annoyance either during construction activities or post construction activities because CSX definitively concluded there would be no vibration impacts in excess of acceptable thresholds. However, under the section in Appendix F titled *Study Findings: General* (page ES-4) it states:

- Numerous vibration events were recorded when there were no train operations in the tunnel. Many of these events produced vibration levels that were of equal or greater magnitude than vibration levels generated from train operations. *It was beyond the scope of this study to determine the specific nature of the events causing these vibrations*. However, neither the frequency nor the magnitudes of these "non-train" vibrations are unusual in an urban environment.

- There was one observed instance in the December 2013 data where a high vibration incident unrelated to train operations occurred during a train passage. This was determined to be a concurrent event by analyzing the vibrations from that same train at other locations along the tunnel. In addition there were numerous additional vibration events not related to train passage that were recorded that were equal or greater than those recorded during train passage.

Using the inverse of logic provided in Appendix F (pg. 4-1) regarding existing land use stating that: "*The Southeast/Southwest Freeway (I-695), located on the north side of the VAT, serves as a "barrier" that creates a discontinuity in vibration path from the proposed project to any sensitive receptors located to the north of the freeway. As a result there will be no vibration impacts from the construction or the trains operations of the proposed project at any of the buildings located north of I-695*"; it would seem reasonable to conclude that the VAT would serve as a barrier that creates a discontinuity in vibration path from the Southeast/Southwest Freeway (I-695) to sensitive receptors to the south of the VAT that would be some of those very same residences located along Virginia Avenue whose occupants are responsible for issuance of the referenced vibration complaints.

If the bulleted items shown above from the *Study Findings* in Appendix F are accurate; is it possible that vibration effects due to the proximity of Metro's Green Line (map provided) near the Navy Yard could be a factor in the noted events or is it possible another unknown source of vibration south of the VAT exist causal of human annoyance? As noted in FTA guidance regarding generalized ground surface vibration curves (Figure 10-1): "*Subways tend to have more vibration problems than at-grade track. This is probably due to two factors: (1)* ***subways are usually located in more densely developed areas****, and (2) the airborne noise is usually a more serious problem for at-grade systems than the ground-borne vibration. Another difference between subway and at-grade track is that the* ***ground-***

***borne vibration from subways tends to be higher frequency** than the vibration from at-grade track, which makes the ground-borne noise more noticeable*."

Additional studies may be needed "*to determine the specific nature of the events causing these vibrations*" with reference to the first bulleted item above. Given statements in the FTA Manual (pg. 8-6) that: "...*it should be pointed out that the vibration control measures developed for rail transit systems are not effective for freight trains. Consequently, any decision to relocate freight tracks closer to sensitive sites should be made with the understanding that the increased vibration impact due to freight rail will be very difficult, if not impossible, to mitigate*"; it may be possible that the technical report findings may require some adjustments.

In the FEIS Executive Summary, CSX stated: "*Train operations during construction not predicted to cause human annoyance or building damage*"; therefore, mitigations were not provided in the environmental documentation because no impact was predicted. Given the noted uncertainty and until it is proven that adjustments to the technical report analysis are not required, as a minimum measure during the interim, **it may be prudent for CSX to reduce the speed of trains transiting the tunnel during the VAT reconstruction.** Until the source of vibration is determined definitively not to be the result of the CSX action that gesture would further validate CSX's commitment as stated on the VAT website that: "*CSX is committed to safely and efficiently upgrading this critical piece of the region's rail system in a way that addresses community concerns and helps leave this great neighborhood even better than it is today*."

As noted in the Record of Decision, Section VII Mitigation Measures – Environmental Commitments: "*The project sponsor has agreed to a number of environmental commitments as mitigation for environmental impacts that will result from the Virginia Avenue Tunnel Reconstruction Project*"; therefore, **mitigation will be required** if the source of vibration causing annoyance complaints in the community adjacent to the project is due to the VAT reconstruction.

With the exception of the complaints noted by the various embedded communications involving the issue of annoyance due to vibration perceived as the result of the VAT reconstruction, CSX appears to be doing a remarkable job in keeping the impacted community engaged, involved and informed concerning VAT construction related issues. In consideration of the aforementioned, it may be in the best interest of CSX, while construction is ongoing, to determine adjustments; if needed, based on judgement and expertise that will confirm the findings in the technical report Appendix F – Vibration Analysis Report.

Sincerely,

Michael Hicks
Environmental Manager/Engineer

Enclosures: Embedded

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Attachment 6

CSX Response Letter to FHWA

William M. Parry, PG, CGWP
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Public Safety & Environment Department
One Bell Crossing
Selkirk, NY 12158

June 6, 2017

Mr. Michael Hicks
Environmental Manager / Engineer
US Department of Transportation
Federal Highway Administration
1990 K Street NW Suite 510
Washington, DC 20006-1103

Subject: Update on CSX Response Actions to FHWA's May 10, 2017 Letter

Dear Mr. Hicks,

This letter is to update the Federal Highway Administration (FHWA) on the continued efforts being taken by CSX to respond to the complaints of vibration in the vicinity of the Virginia Avenue Tunnel project that were raised in your May 10, 2017 letter. As indicated in your letter, we too believe a more definitive understanding of the vibrations is needed in order to make fact based decisions on the necessary future actions.

With respect to developing this more definitive understanding, CSX is implementing a train vibration measurement program in the residential area of the tunnel located closest to the tracks (i.e. 300 block area). The field measurement portion of this program is currently scheduled to be completed by June 10th. Evaluation of the data will include, amongst other things, correlation of the train movements in the tunnel with vibration levels in the tunnel and at the closest residential structure. The data download and evaluation process will take approximately 3 to 4 weeks to complete after completion of the field program.

While this investigation progresses, CSX is taking various other actions in an attempt to physically reduce the vibration levels that may be associated with train movements in the tunnel. These actions include the installation of top of rail friction modifiers to the track on either side of the tunnel, placement of additional ballast to further cushion or insulate the tunnel structure from the tracks and then track resurfacing to further minimize potential vibrations that can occur. The friction modifiers have already been installed. The additional ballast placement and track resurfacing tasks are underway and should be completed within the next couple weeks.

Please let me know if you have any questions or would like some additional information on CSX's actions to address the vibration concerns in the area. We'll keep you posted on our progress as we remain committed to resolving these concerns.

Sincerely,

William M. Parry

cc:: Ravindra Ganvir, DDOT

Attachment 7

Amec/Foster Wheeler Letter to FHWA

September 19, 2017

Mr. Michael Hicks
Environmental Manager / Engineer
US Department of Transportation
Federal Highway Administration
1200 New Jersey Avenue, SE
Washington, DC 20590

Dear Mr. Hicks:

Re: Virginia Avenue Tunnel Vibration Update

This letter is to update the Federal Highway Administration (FHWA) on behalf of our client, CSX Transportation, Inc. (CSXT). In a letter dated June 6, 2017 to FHWA, CSXT outlined efforts to investigate and resolve the rail vibration concerns identified in FHWA's letter dated May 10, 2017.

In June of 2017, CSXT completed various actions to address vibration levels that may be associated with train movements in the tunnel. These actions included the installation of friction modifiers to the track on either side of the tunnel, placement of additional ballast to further cushion or insulate the tunnel structure from the tracks and track resurfacing to further minimize potential vibrations.

In addition, CSXT retained us to assist with a train vibration measurement program in the residential area of the tunnel located closest to the tracks (the 300 block of Virginia Avenue). The purpose of this measurement program was to gain an understanding of the actual vibrations occurring from the train movements, versus those predicted in the project's NEPA documents and Federal Transit Administration (FTA) guidelines. The measurement program was completed in June 2017 with 25 train event measurements completed over two consecutive days.

The results of the train vibration measurement program shows that all train pass-by events are consistently below the FTA criteria for freight rail vibration related to human annoyance as part of the VAT project's Final EIS.

CSXT has shared the results of the measurement program with CH2M, the engineering firm charged by DC Department of Transportation (DDOT) with reviewing the tunnel project. That firm has given us no indication that it disputes our findings. We also understand that CH2M is preparing a report on behalf of DDOT documenting their review of the results from the train pass-by measurement program. We assume that a final copy will be provided to FHWA and CSXT when it is completed. If you have any questions, please feel free to contact me or CSXT directly.

Yours truly,

Amec Foster Wheeler Environment & Infrastructure
a Division of Amec Foster Wheeler Americas Limited

Frank Babic, P.Eng., INCE
Acoustic Practice Lead

cc: Ravindra Ganvir, DDOT
William Parry, CSXT
Chuck Gullakson, CSXT