4.4 Vibration

Regulatory Setting

Unlike noise, construction-related vibration is not addressed within 23 CFR 772 FHWA Procedures for Abatement of Highway Traffic Noise and Construction Noise, amended, effective July 13, 2011. Similarly, there are no state regulations in New Jersey or local laws within Hudson County which address construction-induced vibration.

On a federal level, the best available guidance on evaluating the effects of construction-related vibration is provided within the Federal Transit Administration’s (FTA) Transit Noise and Vibration Impact Assessment guidance manual (FTA-VA-90-1003-06, May 2006). While the Project is not subject to FTA review and approval, this guidance provides vibration source data; vibration propagation equations; and thresholds for evaluating the effects of construction-related vibration. Construction vibration assessment was performed for Resist structures because the construction activities associated with Resist infrastructure pose the greatest risk for structural damage. Vibrationary sheet pile driving was assumed to be performed utilizing a vibratory hammer, while impact pile driving was assumed to be performed through use of an impact pile driving rig. Therefore, the construction vibration assessment was performed for vibratory sheet pile driving and impact pile driving operations. The analysis was performed assuming vibratory sheet pile driving and impact pile driving activities would be necessary along the entire Resist alignment for each of the Build Alternatives. In addition, it was assumed that vibratory sheet pile driving would be necessary for the high-level sewer outfall adjacent to 14th Street for Alternatives 2 and 3 and for the force main outfalls to support DSD at Weehawken Cove for all three Build Alternatives.

Impacts related to construction-generated vibration are typically assessed based on structural damage and annoyance thresholds. Structural damage is based on the PPV of the vibrations (in/sec) and the criteria for assessing damage is based on building material, as presented in Table 4.24. Damage criteria and building category definitions listed in the FTA guidance manual are based on the Swiss Standard SN 640 312a. Vibration assessments were conducted for both Building Category II, which represents “typical” buildings in the Study Area, and Building Category IV, which represents poorly-constructed buildings or those that have pre-existing structural damage and are thereby extremely susceptible to vibration-induced damage. While Category IV may

<table>
<thead>
<tr>
<th>BUILDING CATEGORY</th>
<th>PPV (IN/SEC)</th>
<th>APPROXIMATE LV^{	ext{a}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category I: Buildings of steel or reinforced concrete, such as factories, retaining walls, bridges, steel towers, open channels, underground chambers and tunnels with and without concrete alignment</td>
<td>0.5</td>
<td>102</td>
</tr>
<tr>
<td>Category II: Buildings with foundation walls and floors in concrete, walls in concrete or masonry, stone masonry retaining walls, underground chambers and tunnels with masonry alignments, conduits in loose material</td>
<td>0.3</td>
<td>98</td>
</tr>
<tr>
<td>Category III: Buildings as mentioned above in Category II but with wooden ceilings and walls in masonry</td>
<td>0.2</td>
<td>94</td>
</tr>
<tr>
<td>Category IV: Construction very sensitive to vibration; objects of historic interest</td>
<td>0.12</td>
<td>90</td>
</tr>
</tbody>
</table>

Note: 1 – 1 RMS VdB re 1 micro-inch/second.

include historic buildings, a pre-construction survey will be needed in order to accurately classify Study Area buildings into appropriate categories. Therefore, the goal of this structural damage assessment is to identify the distances from construction activities and approximate the number of buildings where structural damage could occur if those building categories are present within those distances. The lowest damage threshold and a threshold representative of the “average” building was considered in order to be conservative. The PPV of the vibrations above which there is a potential for damage to a structure in Category II buildings is 0.3 in/sec and 0.12 in/sec for Category IV buildings.

Table 4.25  FTA Construction Vibration Annoyance Criteria

<table>
<thead>
<tr>
<th>LAND USE CATEGORY</th>
<th>GBV IMPACT LEVELS (VdB RE 1 MICRO-INCH/SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FREQUENT EVENTS¹</td>
</tr>
<tr>
<td>Category 1: Buildings where vibration would interfere with interior operations</td>
<td>65 VdB¹</td>
</tr>
<tr>
<td>Category 2: Residences and buildings where people normally sleep</td>
<td>72 VdB</td>
</tr>
<tr>
<td>Category 3: Institutional land use with primarily daytime use</td>
<td>75 VdB</td>
</tr>
</tbody>
</table>

Notes:  
¹ “Frequent Events” is defined as more than 70 vibration events of the same source 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 of the same kind per day.

Table 4.26  FTA Construction Vibration Annoyance Criteria for Special Buildings

<table>
<thead>
<tr>
<th>LAND USE CATEGORY</th>
<th>GBV IMPACT LEVELS (VdB RE 1 MICRO-INCH/SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FREQUENT EVENTS¹</td>
</tr>
<tr>
<td>Concert Halls</td>
<td>65 VdB</td>
</tr>
<tr>
<td>TV Studios</td>
<td>65 VdB</td>
</tr>
<tr>
<td>Recording Studios</td>
<td>65 VdB</td>
</tr>
<tr>
<td>Auditoriums</td>
<td>72 VdB</td>
</tr>
<tr>
<td>Theaters</td>
<td>72 VdB</td>
</tr>
</tbody>
</table>

Notes:  
¹ “Frequent Events” is defined as more than 70 vibration events of the same source per day.  
² “Occasional or Infrequent Events” is defined as fewer than 70 vibration events of the same source per day.


Vibration annoyance is evaluated based on vibration velocity levels (Lv) measured in units of VdB. The human perceptibility threshold is approximately 65 VdB, though response to vibration is not usually significant unless the vibration exceeds 70 VdB. Human response to vibration is a complex topic with limited research. The FTA criteria for assessing annoyance due to construction-related vibrations is general and based on land use categories that are presented in Table 4.25.

In accordance with FTA manual guidelines, vibration land use Category 1 is intended to represent other non-residential buildings with high sensitivity such as buildings where vibration-sensitive research and manufacturing is performed, hospitals with vibration-sensitive equipment, and university research operations. Vibration land use Category 2 is intended to represent residences, as well as hotels and hospitals where people sleep. Vibration land use Category 3 is intended to include schools and churches, as well as quiet office buildings where vibration may interfere with activities; however, this category is not intended to include all buildings with office space (e.g., industrial buildings which have office space).

The FTA’s guidance manual also establishes ground-borne vibration limits for a set of land use types, which are extremely sensitive to vibrations and do not fit into the three land use categories described in Table 4.25. These land use types are referred to as ‘special buildings’ and include concert halls, television studios, recording studios, auditoriums, and theaters. Table 4.26 presents vibration annoyance criteria for these ‘special’ building types.

For the construction vibration annoyance assessment, a variety of land uses were identified within the Study Area proximate to the construction operations. Frequent vibration events (i.e., more than 70 events per eight-hour day, per the FTA criterion definition) were assumed; therefore, for Category 3 land use (i.e., institutional land use with primarily daytime use), vibration velocity levels above 75 VdB would be considered annoying. Category 3 land use within the Study Area were identified as primary and secondary schools, churches, Stevens Institute of Technology, and office buildings.

Category 1 (high sensitivity) land use, associated with Stevens Institute of Technology university research operations, were identified within the Study Area. Upon review of the university’s website, Stevens...
maintains several research laboratories within the Engineering, Sciences, Computer Sciences, and Arts and Humanities departments, which host potentially vibration-sensitive operations and include potentially vibration-sensitive equipment. Based on field reconnaissance, in addition to the research labs, classroom laboratories with potentially vibration-sensitive equipment were identified. Vibration velocity levels above 65 VdB would be considered annoying to this land use category.

A vibration annoyance assessment was not performed for residual land use (Category 2). As outlined in the FTA's guidance manual, Category 2 is intended to cover locations where people sleep (e.g., residences, hotels, hospitals, etc.). Therefore, the FTA Category 2 annoyance criterion is intended to represent nighttime sensitivity. As previously stated, the NOHRHC prohibits nighttime work, so the potential for annoyance was not evaluated for FTA Category 2 land use.

In addition to the Category 1 and 3 land use identified, the music and technology department at Stevens Institute of Technology has a recording studio, located in the Morton-Perce-Kidde complex. The University also has several auditoriums (e.g., Edwin A Stevens building and Babbio Center). These facilities would be classified as 'special buildings' under FTA. Vibration velocity levels above 65 VdB would be considered annoying to people utilizing the recording studio, while levels above 72 VdB would be considered annoying in the campus auditoriums. Table 12-2 of FTA's May 2006 guidance manual includes a list of construction equipment with reference vibration source levels in PPV and VdB at a distance of 25 feet. The reference source levels are representative of a variety of measured data. Although soil conditions can affect actual vibrations, FTA guidance states that these reference source levels provide a reasonable estimate for a wide range of soil conditions. For each sheet pile operation, the upper range value of a sonic (vibratory) pile driver was utilized to perform a conservative worst-case analysis. Similarly, the upper range value of a pile driver (impact) was utilized to perform a conservative worst-case analysis.

Reference source levels are propagated to sensitive receivers based on Equations 2 and 3, which are provided in the FTA's guidance manual. Equation 2 was utilized to perform the construction vibration damage assessment and includes a factor “n” to account for the attenuation rate of vibrations through the ground in accordance with FTA procedures. The value of “n” may be varied if detailed soil information is known. An “n” value of 1.5 is representative of “competent soils” (including sand, sandy clays, silty clays, silts, gravel, and weathered rock). Equation 3 was utilized to predict vibration velocity levels for the annoyance assessment.

(2) PPV_{eq_{start}} = PPV_{ref} \times \left( \frac{D}{25} \right)^n; \text{ and}

(3) L_{0v}(D) = L_{0v}(25ft) - 30\log\left(\frac{D}{25}\right)

Where:

PPV_{ref} = reference vibration level in in/sec at 25 feet.

D = distance between source and receptor (feet).

n = attenuation rate of vibrations through the ground.

Equations 2 and 3 were manipulated to determine the distances from the impact and vibratory pile driving operations within which structural damage and annoyance is anticipated for each building type and land use type assessed, respectively. Results of the construction-generated vibration damage assessment for the sheet driving and impact pile driving operations were compared to structural damage and annoyance criteria to assess vibration-related impact.

4.4.2 Environmental Consequences

Construction-related vibration damage assessments for vibratory sheet pile driving and impact pile driving operations were performed for each alternative. As previously detailed, damage analyses were performed for two different building categories: Category II, which is intended to represent the “average” building construction in the Study Area and Category IV, which represents buildings extremely susceptible to vibration damage. A pre-construction survey is needed to classify Study Area buildings into the appropriate category. Modeling procedures are conservative and assume a homogeneous ground type between construction activities and buildings.

Resist structure alignments have been conceptually designed so actual locations of vibratory pile driving versus impact pile driving is unknown at this time. Assuming one sheet or pile is driven at any given time, there is a potential for structural damage as a result of construction of each alternative.

The distances in which there is a potential for structural damage to occur to Building Category II and IV buildings in the Study Area were predicted based on individual vibratory sheet pile and impact pile driving activities along the entire alignment. In addition, the analysis assumed that operations would be separated by enough distance that vibrations from multiple operations would not cumulatively affect buildings within the Study Area. Source levels for vibratory sheet pile driving and impact pile driving assumed conservative source levels provided within guidelines. Examples of structural damage include loosening of paint and small plaster cracks, loosening and falling of plaster, cracks in masonry, structural weakening, affected ability for load support, etc.

Vibration analyses indicate that potential structural damage for Building Category II (“average” building construction) may occur for all such buildings within 45 and 74 feet of vibratory sheet pile and impact pile driving activities, respectively. In addition, potential structural damage for Building Category IV (buildings extremely susceptible to vibration damage) may occur for buildings within 84 and 136 feet of vibratory sheet pile driving and impact pile driving operations, respectively. Minimum distances to potential structural
were performed for Category 1 land use, which impact pile driving operations were performed for each alternative. As previously detailed, analyses were performed for Category 1 land use, which represents buildings where vibration would interfere with interior operations and Category 3 land use, which represents institutional land use with primarily daytime use. Category 3 land use also includes "special buildings," as a result of a recording studio and auditoriums located within Stevens Institute of Technology. Examples of annoyance associated with ground-borne vibration may include perceived movement within buildings, rattling of items such as windows or household objects located on shelving or in cabinets, disruption of vibration-sensitive equipment or activities, etc.

Based on equation 3, described above, potential vibration annoyance distances for each category were developed. Category 1 building occupants within 539 feet of vibratory pile driving and 922 feet of impact pile driving activities have the potential to be annoyed. Category 3 building occupants within 250 feet from vibratory pile driving and 428 feet from impact pile driving activities have the potential to be annoyed. Concert halls, TV studios, and recording studio occupants ("special buildings") within 539 feet of vibratory pile driving and 922 feet of impact pile driving activities have the potential to be annoyed. Auditoriums and theater occupants ("special buildings") within 315 feet of vibratory pile driving and 539 feet of impact pile driving activities have the potential to be annoyed.

Based on vibration source levels provided within the FTA guidance manual, DSD construction-related equipment produce much lower vibration levels than impact and vibratory pile driving activity, which are necessary to install Resist features.

Alternative 1
Figure 4.49 depicts the boundaries of the areas where Category II and Category IV buildings could be potentially impacted by pile driving activities under Alternative 1. Based on a review of aerial mapping, the total number of structures within 74 feet of impact pile driving is 56 and the total number of buildings within 136 feet of impact pile driving is 94. It is important to note that the confirmation of the number of structures identified within the impact driving distances that meet the criteria for either Category II or Category IV buildings would be based on pre-construction surveys.

Under Alternative 1, there is a potential for minor to severe structural impacts to 56 to 94 buildings.

Alternative 2
Figure 4.50 depicts the boundaries of the areas where Category II and Category IV buildings could be potentially impacted by pile driving activities under Alternative 2. Based on a review of aerial mapping, the total number of structures within 74 feet of impact pile driving is 61 and the total number of buildings within 136 feet of impact pile driving is 104. It is important to note that the confirmation of the number of structures identified within the impact driving distances that meet the criteria for either Category II or Category IV buildings would be based on pre-construction surveys.

Notes:
1. Building Category II - Buildings with foundation walls and floors in concrete, walls in concrete or masonry, stone masonry retaining walls, underground chambers and tunnels with masonry alignments, conduits in loose material; Damage Threshold 0.30 in/sec.
2. Building Category IV - Construction very sensitive to vibration; objects of historic interest; Damage Threshold 0.12 in/sec.

Figure 4.49  Structural Damage - Impact Pile Driving - Alternative 1
Figure 4.50 Structural Damage- Impact Pile Driving- Alternative 2
buildings will be based on pre-construction surveys. Under Alternative 2, there is a potential for minor to severe structural impacts to 61 to 104 buildings.

**Alternative 3**

*Figure 4.51 depicts the boundaries of the areas where Category II and Category IV buildings could be potentially impacted by pile driving activities under Alternative 3. Based on a review of aerial mapping, the total number of structures within 74 feet of impact pile driving is 65 and the total number of buildings within 136 feet of impact pile driving is 108. It is important to note that the confirmation of the number of structures identified within the impact driving distances that meet the criteria for either Category II or Category IV buildings will be based on pre-construction surveys. Under Alternative 3, there is a potential for minor to severe structural impacts to 65 to 108 buildings.*

**No Action Alternative**

There would be no vibration impacts on any buildings under the No Action Alternative, nor any vibration-related annoyance.

4.4.3 Mitigation Measures and Best Management Practices in Alternatives 1, 2, And 3

*Based on the results of the vibration assessments, construction has the potential to cause structural damage to Category II buildings (buildings with foundation walls and floors in concrete, walls in concrete or masonry, stone masonry retaining walls, underground chambers, and tunnels with masonry alignments) within 45 feet of vibratory pile driving and 74 feet of impact pile driving. Therefore, in order to mitigate the potential extent of structural damage from impact pile driving, a vibratory hammer may be utilized. Alternatively, piles can be cast-in-place utilizing an auger drill, which reduces potential structural damage to Category II buildings within 11 feet of drilling. In addition, construction has the potential to cause structural damage to Category IV buildings (construction very sensitive to vibration; objects of historic interest) within 84 feet of vibratory pile driving and 136 feet of impact pile driving. Therefore, in order to mitigate the potential extent of structural damage from impact pile driving, utilizing a vibratory hammer for both sheet and pile driving is suggested. Alternatively, piles can be cast-in-place utilizing an auger drill, which reduces the potential to cause structural damage to Category IV buildings to within 20 feet of drilling.*

*As described earlier, vibration annoyance can be anticipated for Category 1 (buildings where vibration would interfere with interior operations) land use, as well as certain ‘special buildings’ (concert halls, TV studios, and recording studios). In addition, vibration annoyance can be anticipated for Category 3 (institutional land use with primarily daytime use) land use. For auditoriums within the Edwin A. Stevens building and Babbio Center, vibration annoyance can be anticipated. Therefore, in order to mitigate vibration annoyance, a vibratory hammer may be utilized for both sheet and pile driving. Alternatively, piles can be cast-in-place utilizing an auger drill. This method reduces the potential to cause vibration annoyance to Category 1 buildings to within 63 feet and Category 3 buildings to within 135 feet of drilling. If Alternative 1 is selected, university research and classroom labs would not experience vibration-induced annoyance if drilled piles are utilized. Further, the recording studio in the Morton-Peirce-Kidde building and auditoriums in the Edwin A. Stevens building and Babbio Center would also not experience annoyance if an auger drill is utilized.*

*While FTA lists use of vibratory hammers and drilled piles as alternative construction methods for reducing impact, these methods may not be feasible everywhere due to schedule delay and cost constraints. Critical locations where alternative construction methods, specifically drilled piles, would be utilized would be identified during final design and specified within contract documents.*

*In addition to alternative construction methods associated with the Resist elements, for both DSD and Resist, establishing construction vibration structural damage response action and stop-work levels are recommended for inclusion within contract documents. Such levels will be established during final design and after pre-construction surveys have been performed to identify the structural integrity of Study Area buildings and other existing pre-construction issues.*

Strong community outreach will be conducted throughout the design and construction process to explain what people should expect to feel during heavy construction and ensure public safety. In-person communications and digital communication through the project website and email updates would provide routine updates to affected residents. Further, in the event that Alternative 1 is selected, detailed coordination with Stevens Institute of Technology must be performed to identify specific vibration-sensitive equipment and research operations that would be on-going during construction, as well as use of the recording studio and auditoriums in the Edwin A. Stevens building and Babbio Center. At that time, specific minimization and avoidance measures will be identified, as needed.

Recommended vibration control measures and standard specifications that should be implemented into contract documents include:

- establish construction vibration structural damage response action and stop-work levels;
- conduct a pre-construction survey of all buildings within 136 feet of the Resist structure, appropriately classify as Category II or Category IV, and identify existing cracks and building conditions;
- require use of drilled piles and specify locations along Resist alignment where this requirement is applicable;
- require the development and implementation of a Vibration Control and Monitoring Plan, which...
Figure 4.51 Structural Damage - Impact Pile Driving - Alternative 3
documents expected vibration levels during driving activities and methods to control vibration;

• require third-party compliance construction vibration monitoring; and

• contractor will be responsible for damage to structures resulting from construction of this project.

Once final engineering and construction staging plans have been completed, the findings of this vibration analysis can be revisited, if required, to determine whether there are any significant changes to the findings and recommendations.