c. Alternative 3A

Impacts from Alternative 3A due to ground-borne vibration from train passbys are not predicted to exceed the FTA frequent impact criteria at FTA Category 1, 2, or 3 land uses (**Table VI-41**). No vibration levels high enough to damage buildings are estimated from operations, including fragile historic buildings.

Levels under Alternative 3A due to ground-borne noise from train passbys are predicted to exceed the FTA *frequent* impact criteria at 156 residences and other FTA Category 2 land-uses (**Table VI-42**). No exceedances of the FTA ground-borne noise impact criteria are predicted at Category 3 land-uses (institutions) with Alternative 3A.

d. Alternative 3C

Impacts from Alternative 3C due to ground-borne vibration from train passbys are not predicted to exceed the FTA frequent impact criteria at FTA Category 1, 2, or 3 land uses (**Table VI-41**). No vibration levels high enough to damage buildings are estimated from operations, including fragile historic buildings.

Levels under Alternative 3C due to ground-borne noise from train passbys are predicted to exceed the FTA *frequent* impact criteria at 168 residences and other FTA Category 2 land-uses (**Table VI-42**). No exceedances of the FTA ground-borne noise impact criteria are predicted at Category 3 land-uses (institutions) with Alternative 3C.

3. Construction Vibration

Ground-borne vibration would be generated from construction activities from the Preferred Alternative (as well as Alternative 3A and 3C), with potential impacts on surrounding areas near the proposed portals and above the proposed tunnels. Tunnel boring machine (TBM) tunneling would be used to bore the four primary train tunnels. Drill and blast excavation would be used to construct cross-passages and ancillary underground structures. TBM tunneling and drill and blast excavation have been evaluated for a preliminary estimate of potential construction vibration impacts, and presented in this section. The assessment of construction vibration included in this section has been completed for the Preferred Alternative; however, it is not expected that construction vibrations from Alternative 3A or Alternative 3C would be substantially different from the Preferred Alternative.

a. Tunnel Boring Machine Vibration Assessment

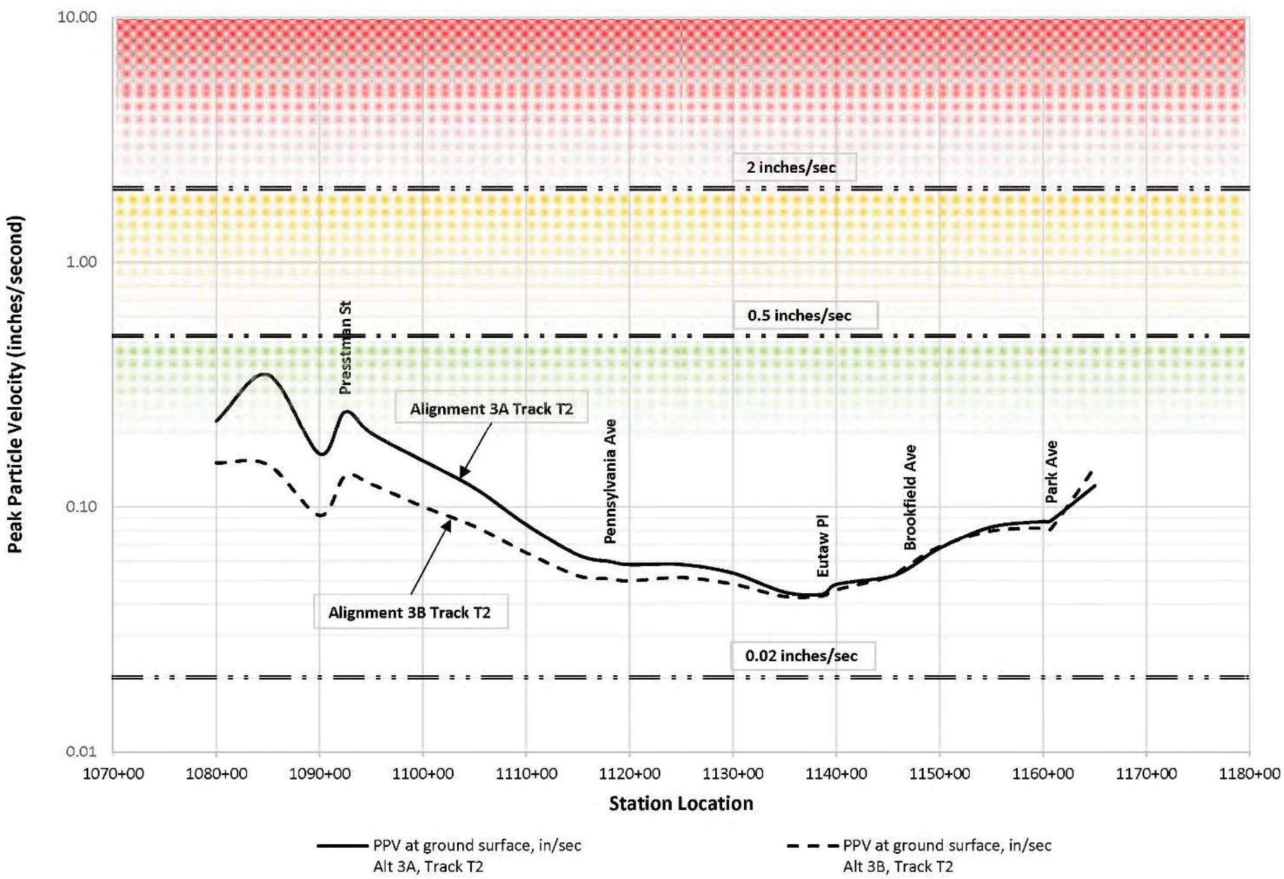
Ground-borne vibrations, which include those generated by TBM tunneling, are transmitted easier and further in hard-rock ground conditions. However, the on-site soils, due to their very dense consistency, have vibration transmitting characteristics close to those of rock. The soil deposit vibration transmission characteristics are essentially the same as rock, based on soil boring data collected for the Baltimore Red Line Project (FTA and MTA, 2012).

The TBM induced ground-borne vibrations attenuate with distance. Construction related ground-borne vibrations are frequently discussed as Peak Particle Velocity (PPV) at a given location. PPVs generally use units of inches per second or millimeters (mm)/second. Damage potential (to structures) as well as disturbance to humans can be related to the Resultant PPV (RPPV) magnitude.

To estimate a vibration attenuation curve, one needs the distance between the source (the TBM) and the receptor (such as a surface structure). For the Preferred Alternative, the distance used is the distance from the TBM tunnel centerline to the ground surface (depth of the tunnel centerline below ground). The vibration attenuation is related to the ground conditions, which are estimated as similar to solid rock as explained above.

Figure VI-25 below presents the estimated PPV at ground surface resulting from TBM construction for the Preferred Alternative. Alternative 3A is included for comparison. Three reference points are shown on this logarithmic plot to help clarify the results. Two inches per second is the level at which potential damage to structures would likely occur. At 0.5 inches per second, old residential structures in poor condition would likely be damaged. Humans are able to sense vibration at approximately 0.02 inches per second. The results show that TBM vibrations during construction would generally be between 0.04 and 0.2 inches per second for the Preferred Alternative, and thus are not likely to risk damaging buildings near or above the proposed tunnels but would be perceptible to humans.

Figure VI-25: Estimated Vibration at Ground Surface from TBM Tunneling



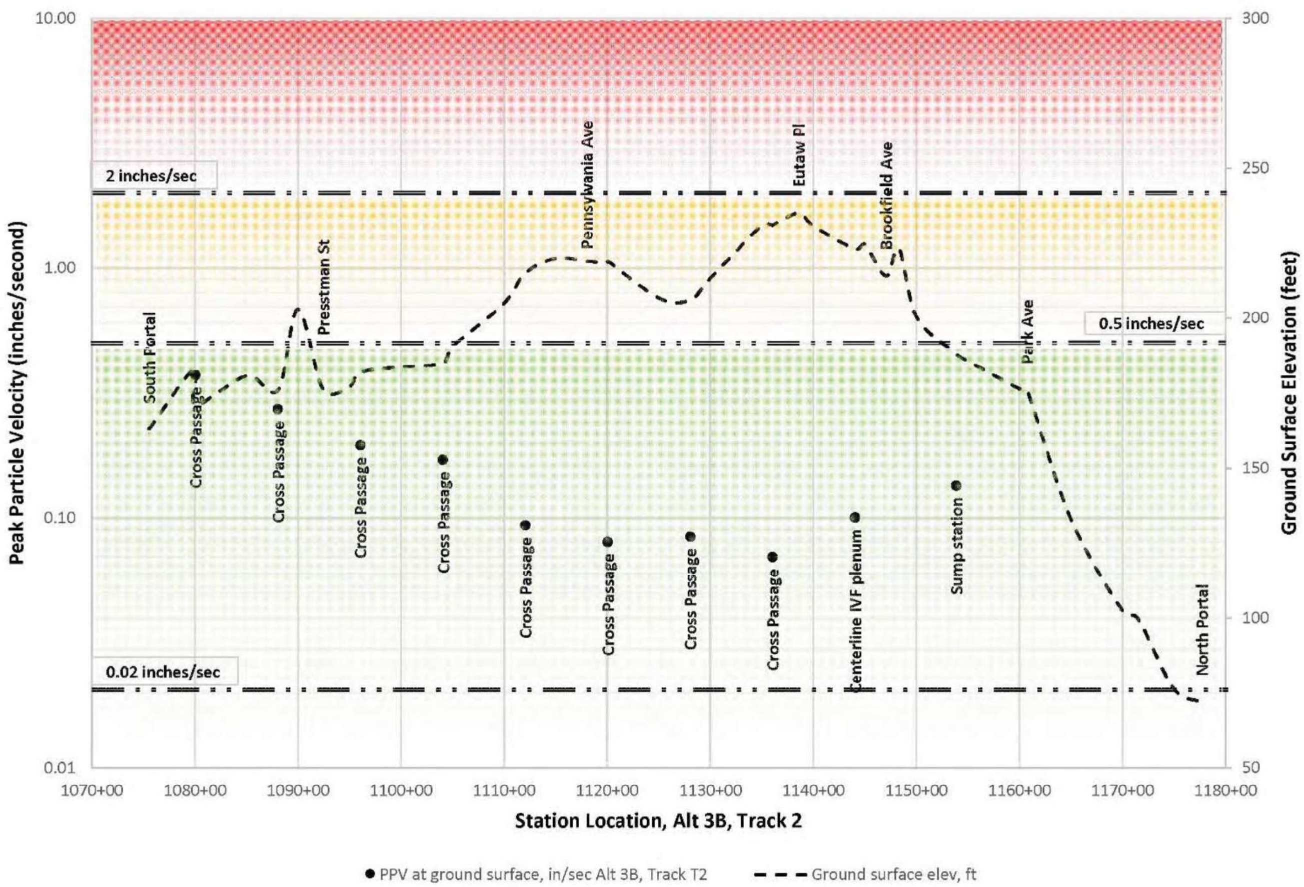
The results indicate that humans would likely be able to sense the vibration from most of the TBM tunneling. Observations show that TBMs closer than 150-160 feet away can be felt by humans, and a good portion of the Preferred Alternative alignment is at or less than this distance. However, the TBM would advance around 30 feet per day, meaning the vibration source would likely only be felt for a short duration before the vibration source moves away from a given location. This means that someone may sense the TBM vibrations for a day or two when tunneling is continuous. One could compare the perceived vibrations to common activities such as traffic or construction equipment. The range of PPVs estimated here would be comparable to the vibration (but not the noise) of a truck traveling 20-30 feet away from an observer.

b. Drill and Blast Tunnel Excavation

The potential vibration effects resulting from tunnel blasting for cross passages and ancillary underground structures was also assessed. Drill and blast tunnel excavation would be used for cross-passages located underground at 16 locations between the south portal and Intermediate Ventilation Facility, one sump station located underground between the Intermediate Ventilation Facility and the south portal, and the intermediate vent cavern, plenum, tunnel and shaft. The intermediate vent plenum would run underneath Jordan Street between approximately Ducatel Street and West North Avenue. In addition, there would be blasting for the egress cavern and tunnel, the North Ventilation Facility, and minor blasting at each portal area.

Current state-of-the-art "controlled blasting" will be specified in the tunnel construction contract, and thus has been assumed in these estimations. Controlled blasting, unlike TBM vibration, is a transient vibration. To control vibrations, the blast holes are fired in a sequential manner at small time intervals resulting in a "rumbling" vibration. In a large tunnel, this rumbling can be sensed for several seconds. The results of this analysis are presented in **Figure VI-26**. The PPV at ground surface in inches per second is depicted as black dots, with one dot per facility that would be constructed with drill and blast excavation under the Preferred Alternative. The continuous dashed line represents the ground surface elevation in feet. The analysis shows that blasting for the Preferred Alternative can be controlled to allow for reasonable advance of excavation activities while controlling vibration to a practical level. No vibration levels would exceed 0.5 inches per second, the level at which damage is likely to occur to old residential buildings in poor condition. The PPVs would generally range between 0.07 to 0.4 inches per second. The threshold for human perception is approximately 0.02 inches per second, however, such vibrations are likely to be barely perceptible.

Figure VI-26: Estimated Vibration at Ground Surface due to Blasting for the Preferred Alternative



c. Drill and Blast Shaft Excavation

The evaluation of blast-induced vibrations for shaft construction is complex and is anticipated to have the most impact to the public. One shaft would be located at the Intermediate Ventilation Facility, and one at the North Ventilation Facility. The magnitude of disturbance from vibrations depends on the construction sequencing and general configuration of the shaft and connecting tunnel. For blasting at shaft areas, both ground-borne vibrations and air overpressures were considered. Air overpressures are vibrations from pressure shock waves being transmitted by the atmosphere. Ground-borne vibrations are typically less disturbing and lower potential for damage during shaft excavation. However, overpressures pose more potential for disturbance when blasting for shafts.

It is anticipated that the distance to the closest adjacent building structures would typically be in the range of 100-200 feet since the immediate surrounding area of the shaft would be a working construction zone. Anticipated PPV vibration levels would be less than approximately 0.25 inches per second and thus below 0.5 inches per second, the typical threshold level of potential damage to historic structures.

Recorded data from past blasting activities in similar conditions can be used to estimate potential order of magnitude of air overpressures, measured in decibels (dB). Based on this data, sound levels could range from about 102 to 145 dB at adjacent structures, without considering potential mitigation measures. For the purpose of comparison, 100 dB is approximately like the overpressure from a motorcycle, and 145 dB would be roughly equivalent to a fire cracker. The latter value, 145 dB, is considered high for blasting; this would be representative of a poorly controlled blast and should be considered an exception rather than typical.

4. Mitigation

Since exceedances of the FTA impact criteria are predicted for the project alternatives, candidate mitigation measures have been identified for operational ground-borne noise. The vibration control measures to mitigate the ground-borne noise impacts predicted by modeling will to be developed during final design. Factors such as the level of impact, cost, and effectiveness of mitigation measures will be considered in determining measures that will be included in the project. All vibration control measures would need to be evaluated in more detail during final design when the track alignments are finalized. Additionally, ground propagation characteristics determined through field measurements would also be required to accurately evaluate the various control measures considered. **Table VI-43** provides a list of potential mitigation measures, the approximate vibration reduction potential, and estimated cost.

Table VI-43: Potential Operational Mitigation Measures

Mitigation Measures	Approximate Vibration Reduction Potential	Approximate Cost
Resilient Fastener	5-10 VdB	$300 per track foot
Ballast Mats	10-15 VdB	$180 per track foot
Resiliently Supported Ties	10-15 VdB	$400 per track foot
Floating Slab Track	15-20 VdB	$600 per track foot
Rail Vibration Absorbers	3-5 VdB	$40 per track foot
Rail Vibration Dampers	3-5 VdB	$40 per track foot

The Project will include development of a Construction Vibration Mitigation Plan during the final design phase in order to mitigate for construction vibrations. The plan will include the following measures where practicable:

- Use controlled blasting construction for vibration mitigation during drill and blast and utilize blast covers when applicable. Test blasting and monitoring of blasting for noise and vibrations at sensitive nearby structures will be implemented.
- Implement contractor control measures to ensure vibration from TBM is kept low enough to avoid damaging historic buildings and remains below applicable FTA impact criteria.
- Implement vibration monitoring program and pre-survey of buildings in tunneling and blasting areas.