Appendix E – Construction Noise and Vibration Assessment

123 SHERMAN AVENUE OFFICE PROJECT CONSTRUCTION NOISE & VIBRATION ASSESSMENT

Palo Alto, California

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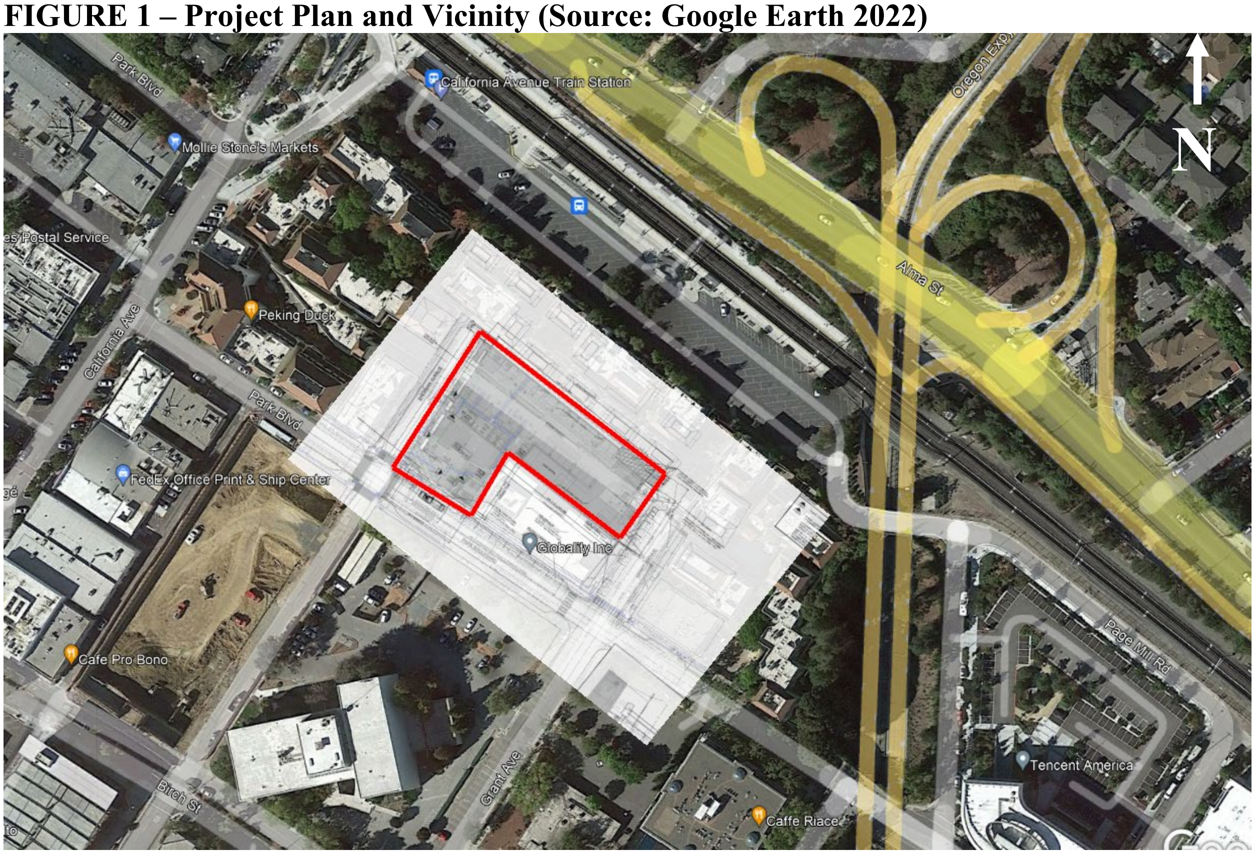
INTRODUCTION

This report summarizes the assessment of potential construction noise and vibration impacts due to the development of an existing site located at 123 Sherman Avenue in Palo Alto, California. A summary of the proposed project, a setting section that includes fundamentals of environmental noise and ground-borne vibration, definitions of the technical terms used in the assessment, the applicable regulatory criteria used in the assessment, and an evaluation of construction related noise and vibration impacts is presented in the sections below.

PROJECT DESCRIPTION

The project site is approximately 0.8-acres and is currently developed with three office buildings and two garage/storage buildings totaling approximately 15,523 square-feet of existing building area along with surface parking. The project would demolish the existing land uses and associated surface parking to construct a three-story, 48,074 square-foot (sf) office building and 3,871-sf of retail uses on the ground floor. Parking would be distributed on the ground floor of the proposed building and on two levels of below-grade parking, totaling 76,899-sf and 172 vehicle parking spaces. Figure 1 shows a Google Earth image of the project plan and vicinity.

FIGURE 1 – Project Plan and Vicinity (Source: Google Earth 2022)



SETTING

Fundamentals of Environmental Noise

Noise may be defined as unwanted sound. Noise is usually objectionable because it is disturbing or annoying. The objectionable nature of sound could be caused by its *pitch* or its *loudness*. *Pitch* is the height or depth of a tone or sound, depending on the relative rapidity (*frequency*) of the vibrations by which it is produced. Higher pitched signals sound louder to humans than sounds with a lower pitch. *Loudness* is intensity of sound waves combined with the reception characteristics of the ear. Intensity may be compared with the height of an ocean wave in that it is a measure of the amplitude of the sound wave.

In addition to the concepts of pitch and loudness, there are several noise measurement scales which are used to describe noise in a particular location. A *decibel (dB)* is a unit of measurement which indicates the relative amplitude of a sound. The zero on the decibel scale is based on the lowest sound level that the healthy, unimpaired human ear can detect. Sound levels in decibels are calculated on a logarithmic basis. An increase of 10 decibels represents a ten-fold increase in acoustic energy, while 20 decibels is 100 times more intense, 30 decibels is 1,000 times more intense, etc. There is a relationship between the subjective noisiness or loudness of a sound and its intensity. Each 10 decibel increase in sound level is perceived as approximately a doubling of loudness over a fairly wide range of intensities. Technical terms are defined in Table 1.

There are several methods of characterizing sound. The most common in California is the *A-weighted sound level (dBA).* This scale gives greater weight to the frequencies of sound to which the human ear is most sensitive. Representative outdoor and indoor noise levels in units of dBA are shown in Table 2.

Because sound levels can vary markedly over a short period of time, a method for describing either the average character of the sound or the statistical behavior of the variations must be utilized. Most commonly, environmental sounds are described in terms of an average level that has the same acoustical energy as the summation of all the time-varying events. This *energy-equivalent sound/noise descriptor* is called L_{eq}. The most common averaging period is hourly, but L_{eq} can describe any series of noise events of arbitrary duration.

The scientific instrument used to measure noise is the sound level meter. Sound level meters can accurately measure environmental noise levels to within about plus or minus 1 dBA. Various computer models are used to predict environmental noise levels from sources, such as roadways and airports. The accuracy of the predicted models depends upon the distance the receptor is from the noise source. Close to the noise source, the models are accurate to within about plus or minus 1 to 2 dBA.

TABLE 1 Definition of Acoustical Terms Used in this Report

Term	Definition
Decibel, dB	A unit describing, the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. The reference pressure for air is 20 micro Pascals.
Sound Pressure Level	Sound pressure is the sound force per unit area, usually expressed in micro Pascals (or 20 micro Newtons per square meter), where 1 Pascal is the pressure resulting from a force of 1 Newton exerted over an area of 1 square meter. The sound pressure level is expressed in decibels as 20 times the logarithm to the base 10 of the ratio between the pressures exerted by the sound to a reference sound pressure (e. g., 20 micro Pascals). Sound pressure level is the quantity that is directly measured by a sound level meter.
Frequency, Hz	The number of complete pressure fluctuations per second above and below atmospheric pressure. Normal human hearing is between 20 Hz and 20,000 Hz. Infrasonic sound are below 20 Hz and Ultrasonic sounds are above 20,000 Hz.
A-Weighted Sound Level, dBA	The sound pressure level in decibels as measured on a sound level meter using the A-weighting filter network. The A-weighting filter de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear and correlates well with subjective reactions to noise.
Equivalent Noise Level, L_{eq}	The average A-weighted noise level during the measurement period.
L_{max}, L_{min}	The maximum and minimum A-weighted noise level during the measurement period.
L_{01}, L_{10}, L_{50}, L_{90}	The A-weighted noise levels that are exceeded 1%, 10%, 50%, and 90% of the time during the measurement period.
Day/Night Noise Level, L_{dn} or DNL	The average A-weighted noise level during a 24-hour day, obtained after addition of 10 decibels to levels measured in the night between 10:00 pm and 7:00 am.
Community Noise Equivalent Level, CNEL	The average A-weighted noise level during a 24-hour day, obtained after addition of 5 decibels in the evening from 7:00 pm to 10:00 pm and after addition of 10 decibels to sound levels measured in the night between 10:00 pm and 7:00 am.
Ambient Noise Level	The composite of noise from all sources near and far. The normal or existing level of environmental noise at a given location.
Intrusive	That noise which intrudes over and above the existing ambient noise at a given location. The relative intrusiveness of a sound depends upon its amplitude, duration, frequency, and time of occurrence and tonal or informational content as well as the prevailing ambient noise level.

Source: Handbook of Acoustical Measurements and Noise Control, Harris, 1998.

TABLE 2 Typical Noise Levels in the Environment

Common Outdoor Activities	Noise Level (dBA)	Common Indoor Activities
	110 dBA	Rock band
Jet fly-over at 1,000 feet		
	100 dBA	
Gas lawn mower at 3 feet		
	90 dBA	
Diesel truck at 50 feet at 50 mph		Food blender at 3 feet
	80 dBA	Garbage disposal at 3 feet
Noisy urban area, daytime		
Gas lawn mower, 100 feet	70 dBA	Vacuum cleaner at 10 feet
Commercial area		Normal speech at 3 feet
Heavy traffic at 300 feet	60 dBA	
		Large business office
Quiet urban daytime	50 dBA	Dishwasher in next room
Quiet urban nighttime	40 dBA	Theater, large conference room
Quiet suburban nighttime		
	30 dBA	Library
Quiet rural nighttime		Bedroom at night, concert hall (background)
	20 dBA	
		Broadcast/recording studio
	10 dBA	
	0 dBA	

Source: Technical Noise Supplement (TeNS), California Department of Transportation, September 2013.

People are usually more sensitive to noise in the nighttime than they are during the daytime. Two factors contribute to this increased sensitivity. First, during the evening and nighttime, outdoor ambient noise levels are generally lower than in the daytime. Most offices and businesses are closed, and automobile traffic has decreased. Second, as household noise levels decrease during the evening, changes in exterior nighttime noise levels can be more noticeable and annoying than such changes are during the day.

To account for this sensitivity, a calculation called the Community Noise Equivalent Level (CNEL) is used to divide the 24-hour day into three time periods: daytime (7:00 a.m. to 7:00 p.m.), evening (7:00 p.m. to 10:00 p.m.), and nighttime (10:00 p.m. to 7:00 a.m.). The evening sound levels are assigned a five decibel penalty (or weighting) and the nighttime sound levels are assigned a 10 decibel penalty (or weighting) prior to averaging with daytime hourly sound levels. In this way, the CNEL is a noise metric that, if used to regulate noise, provides for a quieter evening and nighttime environment.

Effects of Noise

Sleep and Speech Interference

The thresholds for speech interference indoors are about 45 dBA if the noise is steady and above 55 dBA if the noise is fluctuating. Outdoors the thresholds are about 15 dBA higher. Steady noises of sufficient intensity (above 35 dBA) and fluctuating noise levels above about 45 dBA have been shown to affect sleep. Interior residential standards for multi-family dwellings are set by the State of California at 45 dBA DNL. Typically, the highest steady traffic noise level during the daytime is about equal to the DNL and nighttime levels are 10 dBA lower. The standard is designed for sleep and speech protection and most jurisdictions apply the same criterion for all residential uses. Typical structural attenuation is 12-17 dBA with open windows. With closed windows in good condition, the noise attenuation factor is around 20 dBA for an older structure and 25 dBA for a newer dwelling. Sleep and speech interference is therefore possible when exterior noise levels are about 57-62 dBA DNL with open windows and 65-70 dBA DNL if the windows are closed. Levels of 55-60 dBA are common along collector streets and secondary arterials, while 65-70 dBA is a typical value for a primary/major arterial. Levels of 75-80 dBA are normal noise levels at the first row of development outside a freeway right-of-way. In order to achieve an acceptable interior noise environment, bedrooms facing secondary roadways need to be able to have their windows closed, those facing major roadways and freeways typically need special glass windows.

Annoyance

Attitude surveys are used for measuring the annoyance felt in a community for noises intruding into homes or affecting outdoor activity areas. In these surveys, it was determined that the causes for annoyance include interference with speech, radio and television, house vibrations, and interference with sleep and rest. The DNL as a measure of noise has been found to provide a valid correlation of noise level and the percentage of people annoyed. People have been asked to judge the annoyance caused by aircraft noise and ground transportation noise. There continues to be disagreement about the relative annoyance of these different sources. When measuring the percentage of the population highly annoyed, the threshold for ground vehicle noise is about 50 dBA DNL. At a DNL of about 60 dBA, approximately 12 percent of the population is highly annoyed. When the DNL increases to 70 dBA, the percentage of the population highly annoyed increases to about 25-30 percent of the population. There is, therefore, an increase of about 2 percent per dBA between a DNL of 60-70 dBA. Between a DNL of 70-80 dBA, each decibel increase increases by about 3 percent the percentage of the population highly annoyed. People appear to respond more adversely to aircraft noise. When the DNL is 60 dBA, approximately 30-

35 percent of the population is believed to be highly annoyed. Each decibel increase to 70 dBA adds about 3 percentage points to the number of people highly annoyed. Above 70 dBA, each decibel increase results in about a 4 percent increase in the percentage of the population highly annoyed.

Fundamentals of Groundborne Vibration

Ground vibration consists of rapidly fluctuating motions or waves with an average motion of zero. Several different methods are typically used to quantify vibration amplitude. One method is the Peak Particle Velocity (PPV). The PPV is defined as the maximum instantaneous positive or negative peak of the vibration wave. In this report, a PPV descriptor with units of mm/sec or in/sec is used to evaluate construction generated vibration for building damage and human complaints. Table 3 displays the reactions of people and the effects on buildings that continuous or frequent intermittent vibration levels produce. The guidelines in Table 3 represent syntheses of vibration criteria for human response and potential damage to buildings resulting from construction vibration.

Construction activities can cause vibration that varies in intensity depending on several factors. The use of pile driving, and vibratory compaction equipment typically generates the highest construction related groundborne vibration levels. Because of the impulsive nature of such activities, the use of the PPV descriptor has been routinely used to measure and assess groundborne vibration and almost exclusively to assess the potential of vibration to cause damage and the degree of annoyance for humans.

The two primary concerns with construction-induced vibration, the potential to damage a structure and the potential to interfere with the enjoyment of life, are evaluated against different vibration limits. Human perception to vibration varies with the individual and is a function of physical setting and the type of vibration. Persons exposed to elevated ambient vibration levels, such as people in an urban environment, may tolerate a higher vibration level.

Structural damage can be classified as cosmetic only, such as paint flaking or minimal extension of cracks in building surfaces; minor, including limited surface cracking; or major, that may threaten the structural integrity of the building. Safe vibration limits that can be applied to assess the potential for damaging a structure vary by researcher. The damage criteria presented in Table 3 include several categories for ancient, fragile, and historic structures, the types of structures most at risk to damage. Most buildings are included within the categories ranging from “Historic and some old buildings” to “Modern industrial/commercial buildings.” Construction-induced vibration that can be detrimental to the building is very rare and has only been observed in instances where the structure is at a high state of disrepair and the construction activity occurs immediately adjacent to the structure.

The annoyance levels shown in Table 3 should be interpreted with care since vibration may be found to be annoying at lower levels than those shown, depending on the level of activity or the sensitivity of the individual. To sensitive individuals, vibrations approaching the threshold of perception can be annoying. Low-level vibrations frequently cause irritating secondary vibration, such as a slight rattling of windows, doors, or stacked dishes. The rattling sound can give rise to exaggerated vibration complaints, even though there is very little risk of actual structural damage.

TABLE 3 Reaction of People and Damage to Buildings from Continuous or Frequent Intermittent Vibration Levels

Velocity Level, PPV (in/sec)	Human Reaction	Effect on Buildings
0.01	Barely perceptible	No effect
0.04	Distinctly perceptible	Vibration unlikely to cause damage of any type to any structure
0.08	Distinctly perceptible to strongly perceptible	Recommended upper level of the vibration to which ruins and ancient monuments should be subjected
0.1	Strongly perceptible	Virtually no risk of damage to normal buildings
0.25	Strongly perceptible to severe	Threshold at which there is a risk of damage to historic and some old buildings.
0.3	Strongly perceptible to severe	Threshold at which there is a risk of damage to older residential dwellings such as plastered walls or ceilings
0.5	Severe - Vibrations considered unpleasant	Threshold at which there is a risk of damage to newer residential structures

Source: Transportation and Construction Vibration Guidance Manual, California Department of Transportation, April 2020.

REGULATORY BACKGROUND

Regulatory Background - Noise & Vibration

City of Palo Alto Comprehensive Plan 2030. Chapter 4 of the 2030 Comprehensive Plan (Natural Environment) discusses noise. The following goals and policies apply to the construction of the proposed project:

Goal N-6: An environment that minimizes the adverse impacts of noise.

Policy N-6.3 Protect the overall community and especially sensitive noise receptors, including schools, hospitals, convalescent homes, senior and childcare facilities and public conservation land from unacceptable noise levels from both existing and future noise sources, including construction noise.

Policy N-6.5 Protect residential and residentially-zoned properties from excessive and unnecessary noise from any sources on adjacent commercial or industrial properties.

Policy N-6.7 While a proposed project is in the development review process, the noise impact of the project on existing residential land uses, public open spaces and public conservation land should be evaluated in terms of the increase in existing noise levels for the potential for adverse community impact, regardless of existing background noise levels. If an area is below the applicable maximum noise guideline, an increase in noise up to the maximum should not necessarily be allowed.

Policy N-6.11 Continue to prioritize construction noise limits around sensitive receptors, including through limiting construction hours and individual and cumulative noise from construction equipment.

Program N6.11.1 For larger development projects that demand intensive construction periods and/or use equipment that could create vibration impacts, such as the Stanford University Medical Center or major grade separation projects, require a vibration impact analysis, as well as formal, ongoing monitoring and reporting of noise levels throughout the entire construction process pertinent to industry standards. The monitoring plan should identify hours of operation and could include information on the monitoring locations, durations and regularity, the instrumentation to be used and appropriate noise control measures to ensure compliance with the noise ordinance.

City of Palo Alto Municipal Code. The noise ordinance of the City of Palo Alto limits noise levels caused by stationary noise sources and construction on adjacent residential properties. The applicable portions of the noise code are as follows:

9.10.060 Special Provisions.

The special exceptions listed in this section shall apply, notwithstanding the provisions of Sections 9.10.030 through 9.10.050 of the Municipal Code. Said exceptions shall apply only to the extent and during the hours specified in each of the following enumerated exceptions.

(b) Construction. Except for construction on residential property, construction, alteration and repair activities which are authorized by valid city building permit shall be prohibited on Sundays and holidays and shall be prohibited except between the hours of eight a.m. and six p.m. Monday through Friday, nine a.m. and six p.m. on Saturday provided that the construction, demolition or repair activities during those hours meet the following standards:

(1) No individual piece of equipment shall produce a noise level exceeding one hundred ten (110) dBA at a distance of twenty-five (25) feet. If the device is housed within a structure on the property, the measurement shall be made out-side the structure at a distance as close to twenty-five feet from the equipment as possible.

(2) The noise level at any point outside of the property plane of the project shall not exceed one hundred ten (110) dBA.

(3) The holder of a valid construction permit for a construction project in a non-residential zone shall post a sign at all entrances to the construction site upon commencement of construction, for the purpose of informing all contractors and subcontractors, their employees, agents, materialmen and all other persons at the construction site, of the basic requirements of this chapter.

IMPACTS

Construction Noise Impacts

Section 9.10.060(b) of the City of Palo Alto Municipal Code states that construction activities are permitted between the hours of 8:00 a.m. and 6:00 p.m. Monday through Friday and between 9:00 a.m. and 6:00 p.m. on Saturdays provided that no individual piece of equipment produces a noise level exceeding 110 dBA at 25 feet or noise levels of 110 dBA are not exceeded anywhere outside the property plane. If the equipment is housed in a structure, the 110 dBA would be enforced at 25 feet from the structure. All construction activities are prohibited on Sundays and holidays.

Construction activities generate varying levels of noise throughout the construction period. A list of typical maximum instantaneous noise levels measured at 50 feet are provided in Table 4. Maximum noise levels typically range from about 80 to 90 dBA L_{max} at 50 feet from the noise source. Typical hourly average construction-generated noise levels for office building projects are about 75 to 89 dBA L_{eq} measured at 50 feet from the center of the site during busy construction periods (e.g., earth moving equipment, impact tools, etc.), as shown in Table 5.

TABLE 4 Construction Equipment 50-foot Noise Emission Limits

Equipment Category	L_{max} Level (dBA)[1,2]	Impact/Continuous
Arc Welder	73	Continuous
Auger Drill Rig	85	Continuous
Backhoe	80	Continuous
Bar Bender	80	Continuous
Boring Jack Power Unit	80	Continuous
Chain Saw	85	Continuous
Compressor[3]	80	Continuous
Concrete Mixer	85	Continuous
Concrete Pump	82	Continuous
Concrete Saw	90	Continuous
Concrete Vibrator	80	Continuous
Crane	85	Continuous
Dozer	85	Continuous
Excavator	85	Continuous
Front End Loader	80	Continuous
Generator	82	Continuous
Generator (25 KVA or less)	70	Continuous
Gradall	85	Continuous
Grader	85	Continuous
Grinder Saw	85	Continuous
Horizontal Boring Hydro Jack	80	Continuous
Hydra Break Ram	90	Impact
Impact Pile Driver	105	Impact
Insitu Soil Sampling Rig	84	Continuous
Jackhammer	85	Impact
Mounted Impact Hammer (hoe ram)	90	Impact
Paver	85	Continuous
Pneumatic Tools	85	Continuous
Pumps	77	Continuous
Rock Drill	85	Continuous
Scraper	85	Continuous
Slurry Trenching Machine	82	Continuous
Soil Mix Drill Rig	80	Continuous
Street Sweeper	80	Continuous
Tractor	84	Continuous
Truck (dump, delivery)	84	Continuous
Vacuum Excavator Truck (vac-truck)	85	Continuous
Vibratory Compactor	80	Continuous
Vibratory Pile Driver	95	Continuous
All other equipment with engines larger than 5 HP	85	Continuous

Notes:

1 Measured at 50 feet from the construction equipment, with a "slow" (1 sec.) time constant.

2 Noise limits apply to total noise emitted from equipment and associated components operating at full power while engaged in its intended operation.

3 Portable Air Compressor rated at 75 cfm or greater and that operates at greater than 50 psi.

Source: Mitigation of Nighttime Construction Noise, Vibrations and Other Nuisances, National Cooperative Highway Research Program, 1999.

TABLE 5 Typical Ranges of Construction Noise Levels at 50 Feet, L_{eq} (dBA)

	Domestic Housing		Office Building, Hotel, Hospital, School, Public Works		Industrial Parking Garage, Religious Amusement & Recreations, Store, Service Station		Public Works Roads & Highways, Sewers, and Trenches	
	I	**II**	**I**	**II**	**I**	**II**	**I**	**II**
Ground Clearing	83	83	84	84	84	83	84	84
Excavation	88	75	89	79	89	71	88	78
Foundations	81	81	78	78	77	77	88	88
Erection	81	65	87	75	84	72	79	78
Finishing	88	72	89	75	89	74	84	84

I - All pertinent equipment present at site.
II - Minimum required equipment present at site.

Source: U.S.E.P.A., Legal Compilation on Noise, Vol. 1, p. 2-104, 1973.

Project construction is expected to start in March 2023 and would be built out over a period of approximately 16 months (to be completed by July 2024). The construction of the proposed project would involve demolition, site preparation, grading, trenching, building exterior, architectural coating/building interior and paving as per the supplied construction data sheet. During each stage of construction, there would be a different mix of equipment operating, and noise levels at nearby properties would vary by stage and vary within stages, based on the amount of equipment in operation and the location at which the equipment is operating.

The Federal Highway Administration's (FHWA's) Roadway Construction Noise Model (RCNM) was used to calculate the maximum and hourly average noise levels for each phase of construction, assuming all equipment within a phase would operate simultaneously, for a worst case scenario (Table 6). This construction noise model includes representative sound levels for the most common types of construction equipment and the approximate usage factors of such equipment that were developed based on an extensive database of information gathered during the construction of the Central Artery/Tunnel Project in Boston, Massachusetts (CA/T Project or "Big Dig"). The usage factors represent the percentage of time that the equipment would be operating at full power.

Standard methods for acoustical analysis of construction sites are based on the distance from the "acoustical center" or construction activity center of the site to the nearest noise-sensitive receptor, as was the case for this analysis. In other words, the proposed pieces of construction equipment are not modeled at the construction area boundary, but rather at the approximate center of the area in which most construction activity is likely to occur.

The nearest noise sensitive receptors in the vicinity of the project site include residences and commercial properties (Figure 2, R – Residences, C – Commercial properties). The residences (R1, R2, R3) are located at a distance of 65 feet to the north of the 'acoustic center' of the site, while the closest commercial property (C1) is located about 40 feet to the southeast of the acoustic center adjacent to the project site.

FIGURE 2 – Project site with nearest noise sensitive receptors (Source: Google Earth 2022)

TABLE 6 Calculated L_{max} and L_{eq} Construction Noise Levels at 25 feet

Construction Phase	Equipment	Quantity	Calculated Noise Levels (dBA) at 25 feet	
			L_{max}*	L_{eq}
Demolition	Concrete/Industrial Saws	1	96	92
	Excavators	1		
	Rubber Tired Dozers	1		
	Tractors/Loaders/Backhoes	1		
Site Preparation	Graders	1	91	89
	Rubber Tired Dozers	1		
Grading/Excavation	Excavators	1	91	90
	Graders	1		
	Tractors/Loaders/Backhoes	1		
Trenching/Foundation	Tractors/Loaders/Backhoes	1	90	88
	Excavators	1		
	Cranes	1		
Building - Exterior	Cranes	1	90	88
	Forklifts	1		
	Tractors/Loaders/Backhoes	1		
	Welders	1		
	Aerial Lift	2		
Building - Interior/Architectural Coating	Air compressors	1	87	82
	Cranes	1		
Paving	Cement and Mortar mixers	1	90	89
	Pavers	1		
	Paving Equipment	1		
	Rollers	1		
	Tractors/Loaders/Backhoes	1		

* Total L_{max} is the value for the loudest piece of equipment

Based on calculated maximum and hourly average noise levels for construction equipment in each phase as shown in Table 6, noise levels for the proposed construction would range from 87 to 96 dBA L_{max} and from 82 to 92 dBA L_{eq} at 25 feet from the center of the construction activities, assuming that all the equipment could be operated simultaneously. Construction-generated noise levels drop off at a rate of about 6 dBA per doubling of the distance between the source and receptor. Shielding by buildings or terrain can provide an additional 5 to 10 dBA noise reduction at distant receptors.

Noise levels at the residences would range from a maximum level of 78 to 87 dBA L_{max} and 74 to 84 dBA L_{eq} at about 65 feet. At the closest commercial property (about 40 feet away), noise levels are anticipated to reach maximum levels of 83 to 92 dBA L_{max} and 78 to 88 dBA L_{eq} at 40 feet from the acoustical center of the construction activities at the project site.

Theoretically, noise levels could reach a maximum level of about 104 dBA L_{max} and 100 dBA L_{eq} at a distance of 10 feet from the edge of the property plane assuming all equipment were operating at this position. Typically, however construction equipment would not all be placed directly at the property plane, which would result in noise levels well below the 110 dBA threshold at any point beyond the property plane of the construction site. In other words, no individual piece of equipment would exceed 110 dBA at a distance of 25 feet. Further, 110 dBA would also not be exceeded at any point beyond the property plane of the construction site during allowable hours. Although the impact is considered less-than-significant, the incorporation of the following construction best management practices should be considered as part of the conditions of approval, given the proximity of the site to nearby land uses.

Construction Best Management Practices

- Construction will be limited to the hours of 8:00 a.m. to 6:00 p.m. Monday through Friday and between 9:00 a.m. and 6:00 p.m. on Saturdays for any on-site or off-site work within 300 feet of any residential unit.

- The contractor shall use "new technology" power construction equipment with state-of-the-art noise shielding and muffling devices. All internal combustion engines used on the project site shall be equipped with adequate mufflers and shall be in good mechanical condition to minimize noise created by faulty or poorly maintained engines or other components.

- Construct temporary noise barriers, where feasible, to screen adjoining land uses. Temporary noise barrier fences would provide a 5 dBA noise reduction if the noise barrier interrupts the line-of-sight between the noise source and receptor and if the barrier is constructed in a manner that eliminates any cracks or gaps.

- The unnecessary idling of internal combustion engines shall be prohibited.

- Staging areas and stationary noise-generating equipment shall be located as far as possible from noise-sensitive receptors, such as residential uses (a minimum of 200 feet).

- Ensure that generators, compressors, and pumps are housed in acoustical enclosures.

- Locate cranes as far from adjoining noise-sensitive receptors as possible.

- During final grading, substitute graders for bulldozers, where feasible. Wheeled heavy equipment are quieter than track equipment and should be used where feasible.

- Substitute nail guns for manual hammering, where feasible.

- Substitute electrically powered tools for noisier pneumatic tools, where feasible.

- The surrounding neighborhood shall be notified early and frequently of the construction activities.
- A "noise disturbance coordinator" shall be designated to respond to any local complaints about construction noise. The disturbance coordinator would determine the cause of the noise complaints (e.g., beginning work too early, bad muffler, etc.) and institute reasonable measures warranted to correct the problem. A telephone number for the disturbance coordinator would be conspicuously posted at the construction site.

Mitigation Measures: **No further mitigation required.**

Construction Vibration Impacts

Proposed construction phases would include demolition, site preparation, grading/excavation, trenching/foundation, building exterior, building interior/architectural coating and paving. Perceptible vibration may occur when heavy equipment or impact tools are used in close proximity to sensitive receptors. However, the proposed project would not require pile driving, which can cause excessive vibration.

The City of Palo Alto does not specify a construction vibration limit. For structural damage, the California Department of Transportation recommends a vibration limit of 0.5 in/sec PPV for buildings structurally sound and designed to modern engineering standards, 0.3 in/sec PPV for buildings that are found to be structurally sound but where structural damage is a major concern, and a conservative limit of 0.25 in/sec PPV for historic and some old buildings. A review of the City of Palo Alto Master List of Structures on the Historic Inventory indicates that there are no historic or old buildings near the project site. Therefore, the 0.3 in/sec PPV vibration limit would be applicable to properties in the immediate vicinity of the project site.

Vibration levels would vary depending on soil conditions, construction methods, and equipment used. Vibration levels are highest close to the source, and then attenuate with increasing distance at the rate $(D_{ref}/D)^{1.1}$, where D is the distance from the source in feet, and D_{ref} is the reference distance of 25 feet. Table 7 presents typical vibration levels that could be expected from construction equipment at 25 feet and summarizes the minimum distances needed from each equipment to meet the 0.3 in/sec PPV vibration threshold.

TABLE 7 Construction Vibration Levels at Nearby Buildings

Equipment		PPV (in/sec)			Minimum Distance to meet threshold (feet)
		Source Level (25 ft)	At 10 ft	At 5 ft	0.3 in/sec PPV
Clam shovel drop		0.202	0.553	1.186	20
Hydromill (slurry wall)	in soil	0.008	0.022	0.047	<5
	in rock	0.017	0.047	0.100	<5
Vibratory Roller		0.210	0.575	1.233	20
Hoe Ram		0.089	0.244	0.523	10
Large bulldozer		0.089	0.244	0.523	10
Caisson drilling		0.089	0.244	0.523	10
Loaded trucks		0.076	0.208	0.446	10
Jackhammer		0.035	0.096	0.206	<5
Small bulldozer		0.003	0.008	0.018	<5

Source: Transit Noise and Vibration Impact Assessment Manual, Federal Transit Administration, Office of Planning and Environment, U.S. Department of Transportation, FTA Report No. 0123, September 2018, as modified by Illingworth & Rodkin, Inc., June 2022.

Residences and commercial properties surround the project site at a distance of 10 feet with the closest property located at a distance of 5 feet (2555 Park Boulevard). Based on the calculated distances to meet vibration damage thresholds in Table 7 above, vibration due to project construction would exceed the 0.3 in/sec PPV threshold at all surrounding sites, assuming that each piece of equipment would operate along the nearest boundary of the site for a worst-case scenario. At 10 feet, vibration levels are calculated to reach up to 0.553 in/sec PPV for a clam shovel drop and up to 0.575 in/sec PPV for a vibratory roller. Vibration levels could reach a maximum of 1.186 in/sec PPV for a clam shovel drop and 1.233 in/sec PPV for a vibratory roller for the closest receptor at a distance of 5 feet away.

Construction vibration received at off-site buildings would be dependent on the distance between individual pieces of equipment on the project site and the off-site building. For example, a vibratory roller operating near the project site boundary would generate the worst-case vibration levels for the building sharing that property line. Construction vibration impacts are assessed based on the potential for damage to buildings on receiving land uses, not at receptors at the nearest property lines. Therefore, the distance used to propagate construction vibration levels (as shown in Table 7) was estimated under the assumption that each piece of equipment could operate along the nearest boundary of the project site representing the worst-case scenario.

The US Bureau of Mines has analyzed the effects of blast-induced vibration on buildings in USBM RI 8507,[1] and these findings have been applied to vibrations emanating from construction equipment on buildings.[2] As reported in USBM RI 8507 and reproduced by Dowding, Figure 3 presents the damage probability, in terms of “threshold damage,” “minor damage,” and “major damage,” at varying vibration levels. Threshold damage, which is described as cosmetic damage in this report, would entail hairline cracking in plaster, the opening of old cracks, the loosening of paint or the dislodging of loose objects. Minor damage would include hairline cracking in masonry or the loosening of plaster, and major structural damage would include wide cracking or shifting of foundation or bearing walls.

As shown in Figure 3, maximum vibration levels of 1.233 in/sec PPV would result in approximately 20% probability of threshold damage or cosmetic damage, and no probability of minor or major damage for construction occurring at 5 feet from the edge of the property for the closest receptor. For residential receptors located 10 feet away from the edge of the property to the north, maximum vibration levels of 0.575 in/sec would result in approximately 7% probability of threshold or cosmetic damage and no minor or major damage would be observed.

At locations in other surrounding areas where vibration would not be expected to cause structural damage, vibration levels may still be perceptible. However, as with any type of construction, this would be anticipated and would not be considered significant, given the intermittent and short duration of the phases that have the highest potential of producing vibration. By use of administrative controls, such as notifying neighbors of scheduled construction activities and scheduling construction activities with the highest potential to produce perceptible vibration during hours with the least potential to affect nearby residences, perceptible vibration can be kept to a minimum.

Construction Vibration Mitigation Measures:

The project shall implement the following measures, in addition to the best practices specified in Construction Noise section of this report, to minimize the impacts of groundborne vibration.

Construction Vibration Monitoring, Treatment, and Reporting Plan: The project proponent shall implement a construction vibration monitoring plan to document conditions prior to, during, and after vibration generating construction activities. All plan tasks shall be undertaken under the direction of a licensed Professional Structural Engineer in the State of California and be in accordance with industry-accepted standard methods.

The construction vibration monitoring plan shall include, but not be limited to, the following measures:

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3 Siskind, D.E., M.S. Stagg, J.W. Kopp, and C.H. Dowding, Structure Response and Damage Produced by Ground Vibration form Surface Mine Blasting, RI 8507, Bureau of Mines Report of Investigations, U.S. Department of the Interior Bureau of Mines, Washington, D.C., 1980.

2 Dowding, C.H., Construction Vibrations, Prentice Hall, Upper Saddle River, 1996.

- The report shall include a description of measurement methods, equipment used, calibration certificates, and graphics as required to clearly identify vibration-monitoring locations.

- A list of all heavy construction equipment to be used for this project and the anticipated time duration of using the equipment that is known to produce high vibration levels (clam shovel drops, vibratory rollers, hoe rams, large bulldozers, caisson drillings, loaded trucks, jackhammers, etc.) shall be submitted to the Director of Planning or Director's designee of the Department of Planning, Building and Code Enforcement by the contractor. This list shall be used to identify equipment and activities that would potentially generate substantial vibration and to define the level of effort required for continuous vibration monitoring. Phase demolition, earth-moving, and ground impacting operations so as not to occur during the same time period.

- Where possible, use of the heavy vibration-generating construction equipment shall be prohibited within 20 feet of any adjacent building.
    - Smaller equipment to minimize vibration levels to below 0.3 in/sec PPV shall be used at the property lines adjoining adjacent buildings. For example, a smaller vibratory roller, such as the Caterpillar model CP433E vibratory compactor, could be used when compacting materials within 30 feet of the adjacent conventional building.
    - Avoid using vibratory rollers and clam shovel drops within 30 feet of sensitive areas.
    - Select demolition methods not involving impact tools.
    - Avoid dropping heavy equipment and use alternative methods for breaking up existing pavement, such as a pavement grinder, instead of dropping heavy objects, within 30 feet of the adjacent conventional buildings.

- Document conditions at all structures located within 50 feet of construction prior to, during, and after vibration generating construction activities. All plan tasks shall be undertaken under the direction of a licensed Professional Structural Engineer in the State of California and be in accordance with industry-accepted standard methods. Specifically:

    - Vibration limits shall be applied to vibration-sensitive structures located within 20 feet of construction activities identified as sources of high vibration levels.

    - Performance of a photo survey, elevation survey, and crack monitoring survey for each structure of normal construction within 20 feet of construction activities identified as sources of high vibration levels. Surveys shall be performed prior to any construction activity, in regular intervals during construction, and after project completion, and shall include internal and external crack monitoring in structures, settlement, and distress, and shall document the condition of foundations, walls and other structural elements in the interior and exterior of said structures.

- Develop a vibration monitoring and construction contingency plan to identify structures where monitoring would be conducted, set up a vibration monitoring schedule, define structure-specific vibration limits, and address the need to conduct photo, elevation, and crack surveys to document before and after construction conditions. Construction contingencies shall be identified for when vibration levels approached the limits of 0.3 in/sec PPV.

- At a minimum, vibration monitoring shall be conducted during demolition and excavation activities.

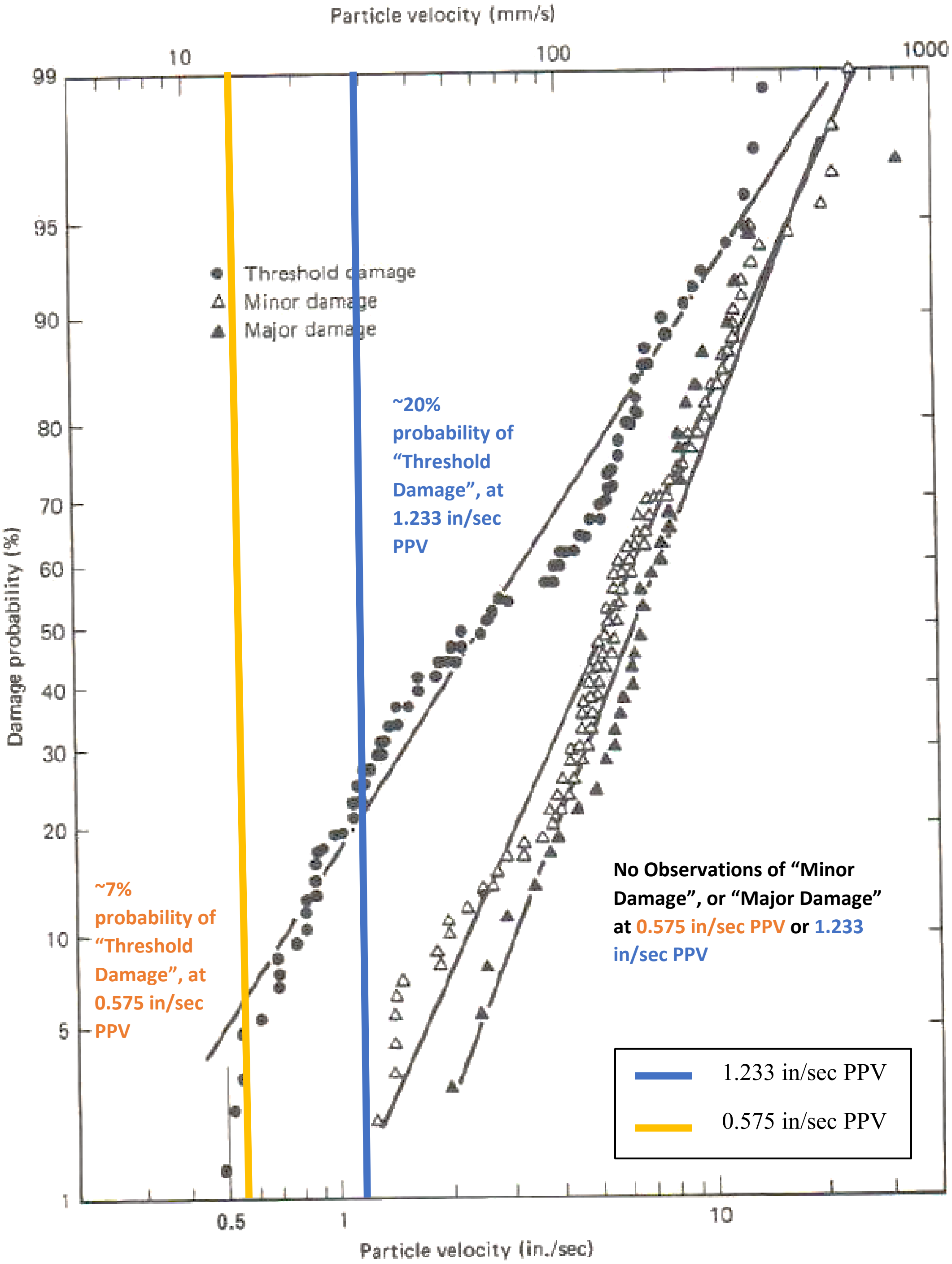
- If vibration levels approach limits, suspend construction and implement contingency measures to either lower vibration levels or secure the affected structures.

- Designate a person responsible for registering and investigating claims of excessive vibration. The contact information of such person shall be clearly posted on the construction site.

- Conduct a post-construction survey on structures where either monitoring has indicated high vibration levels or complaints of damage has been made. Make appropriate repairs or compensation where damage has occurred as a result of construction activities.

The implementation of these measures would reduce the impact to a **less-than-significant level**.

FIGURE 3 Probability of Cracking and Fatigue from Repetitive Loading



Source: Dowding, C.H., Construction Vibrations, Prentice Hall, Upper Saddle River, 1996 as modified by Illingworth & Rodkin, Inc., June 2022.