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October 1, 2024

Chase Davis
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1761 CT 12
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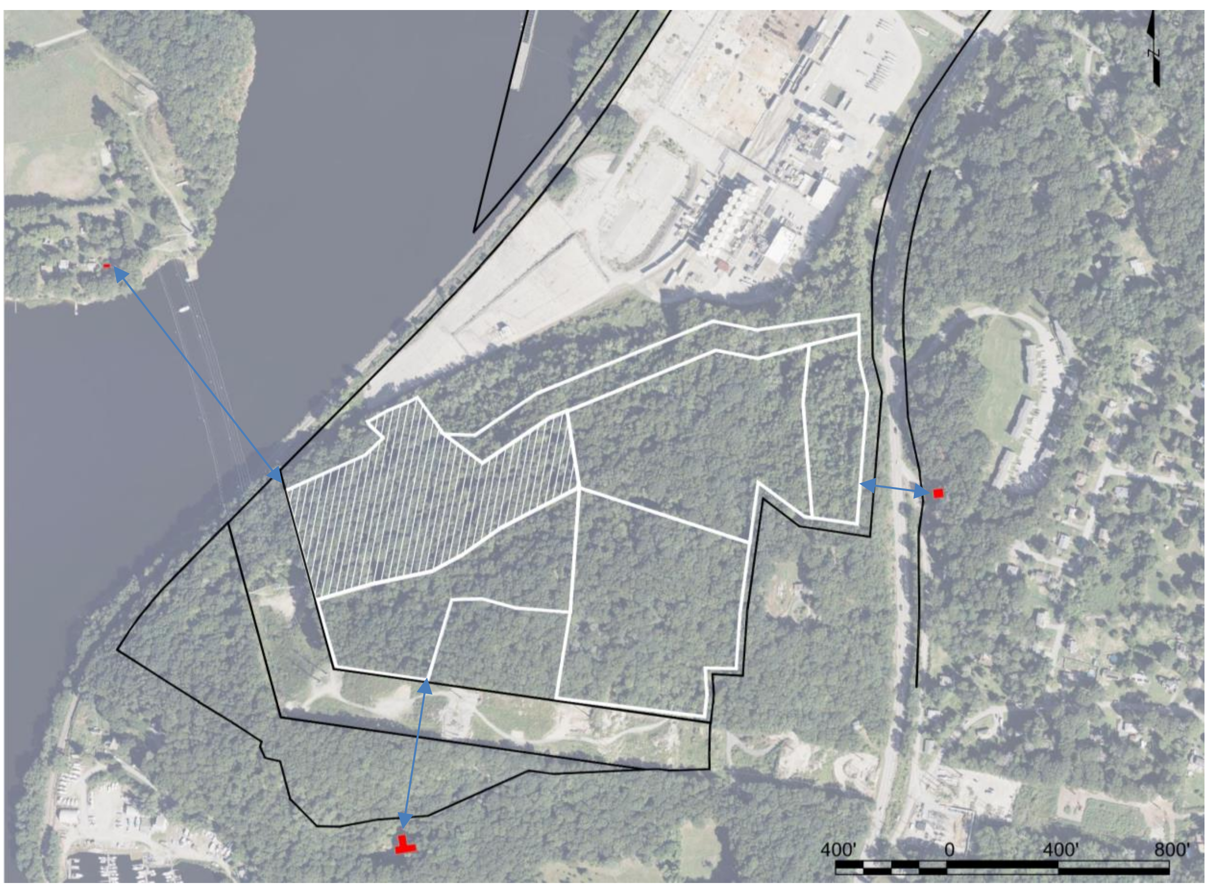
Subject: Gales Ferry Project
Vibration Impact Analysis

Mr. Davis,

Sauls Seismic, LLC (Sauls) has reviewed the data submitted to provide expected maximum vibration and air overpressure levels from both blasting and site construction activities at the closest off-site homes in each direction from the Gales Ferry project.

The closest locations were determined to be 22 Anderson Drive (east), 40 Chapman Lane (south) and 89 Point Breeze Road (west) as indicated in the aerial image below.



Measurements on the aerial image above show the closest distance from each of the off-site locations to any of the blasting operations. These distances, 22 Anderson Drive (260 ft), 40 Chapman Lane (562 ft) and 89 Point Breeze Road (1,018 ft), are used for our calculations below.

Understanding Vibration and Damage Levels

Significant vibration-related research has been a result of blasting activities. This research has investigated the response of structures to vibration. Ground vibrations from blasting and other vibration-related activities can be monitored using portable seismographs. Seismographs measure ground motion using a transducer (sometimes called a geophone). The transducer monitors ground motion in three perpendicular directions. These directions are up and down, left and right, and front and back. These directions are typically referred to as Vertical, Transverse and Radial (sometimes called Longitudinal). For vibration monitoring to be effective, a safe limit must be determined. Many studies have been performed to evaluate safe vibration levels for structures.

Peak Particle Velocity

The most common measurement used for analyzing vibration induced damage is the Peak Particle Velocity (PPV). The PPV is simply a measurement of how fast the ground moves, and it is typically measured in inches per second (in/sec). The PPV is the highest particle velocity recorded during the entire vibration event on any of the three directions monitored by the seismograph. The PPV will also include a corresponding frequency for the ground vibration, which is essential for calculating the actual displacements and strains. The PPV and frequency are commonly used for specifying vibration limits because cracking does not occur until the strain exceeds the failure limit of the material.

Safe Vibration Limits

According to research, damage from vibration does not typically occur until vibration levels are well over 2.0 in/sec.

> "On the average, only minor damage is observed for peak particle velocities of 5.4 inches per second, and major damage is observed for peak particle velocities of 7.6 inches per second."
>
> "The above criterion for safe blasting is considered to hold over a wide variety of soil and rock conditions because the original data were obtained for a wide range of soil and rock conditions and on various types of residential structures."[1]

The United States Bureau of Mines (USBM) conducted many studies to determine a safe vibration level for residential structures. Their recommendation was a vibration limit that varies according to the frequency of the vibration. The USBM recommends lower vibration levels at lower frequency and allows for higher vibration levels at higher frequencies.

> "Practical safe criteria for blasts that generate low-frequency ground vibrations are 0.75 in/sec for modern gypsum board houses and 0.50 in/sec for plaster on lath interiors. For frequencies above 40 Hz, a safe particle velocity maximum of 2.0 in/sec is recommended for all houses."[2]

Blasting in granite typically results in frequencies greater then 40Hz at close in locations.

Many states, counties, and cities have adopted the USBM recommendation as a safe guideline for vibration from blasting activities. In addition, USBM recommendations have been adopted as a safe limit in the National Fire Prevention Association's (NFPA) standards for local fire marshals to use in conjunction with blasting activities and adopted in whole or in part by the Federal Office

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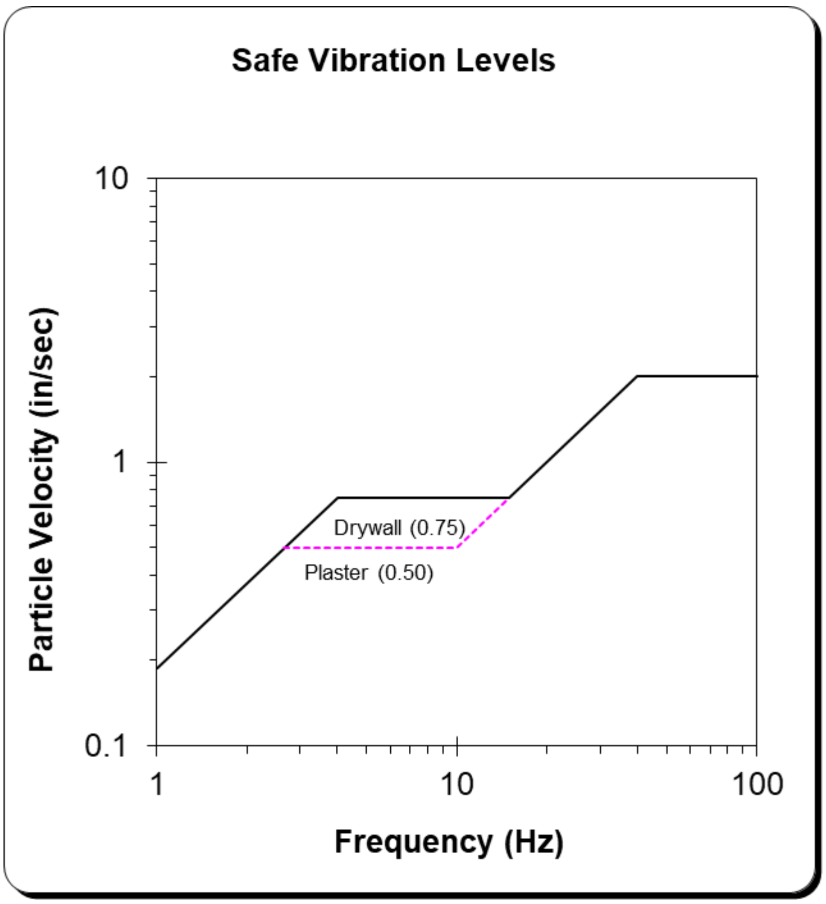
[1] Review of Criteria for Estimating Damage to Residences from Blasting Vibrations Work on manuscript completed April 1961. Supervisory Physicist, Wilbur I. Duvall, David E. Fogelson, Geophysicist.

[2] US Bureau of Mines RI 8507 "Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting", Page 68

of Surface Mining Reclamation and Enforcement (OSM), the insurance industry through the American Insurance Services Group (ASIG, 1990), and the American National Standards Institute (ANSI A10.7, 1998).

These limits "remain the most restrictive criteria in existence that are based upon measured structural responses and observations of cracking correlated to specific vibration events. They provide a guaranteed safe level to guide blasting practices and limits suitable for regulations. They account for the widest possible range and worse-case conditions for low-rise residential structures."[3]

Regulatory limits on vibration levels at structures near blasting activities have been developed to prevent threshold damage from vibrations to adjacent structures.



Environmental Changes and Vibrations

Scientific research on blast effects has measured the effects of normal environmental stresses, as they compare to vibration levels. Even low levels of environmental stress are found to exceed stress levels from the maximum allowable limits for vibration. Seasonal and cyclic changes in temperature and humidity combined with changes in the moisture content of the soils supporting an above-ground structure are generally expected to cause some movement within a structure. Such environmental changes often cause more stress to a structure than typical vibration-causing activities (see graph below).

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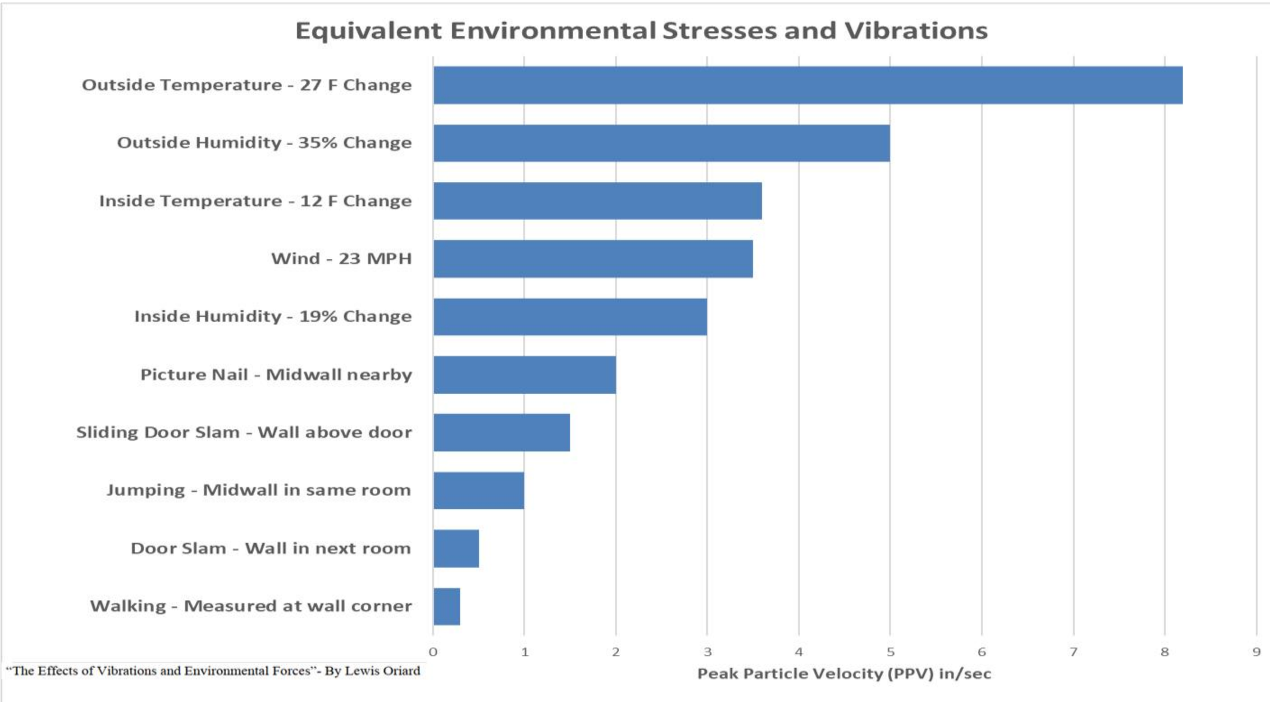
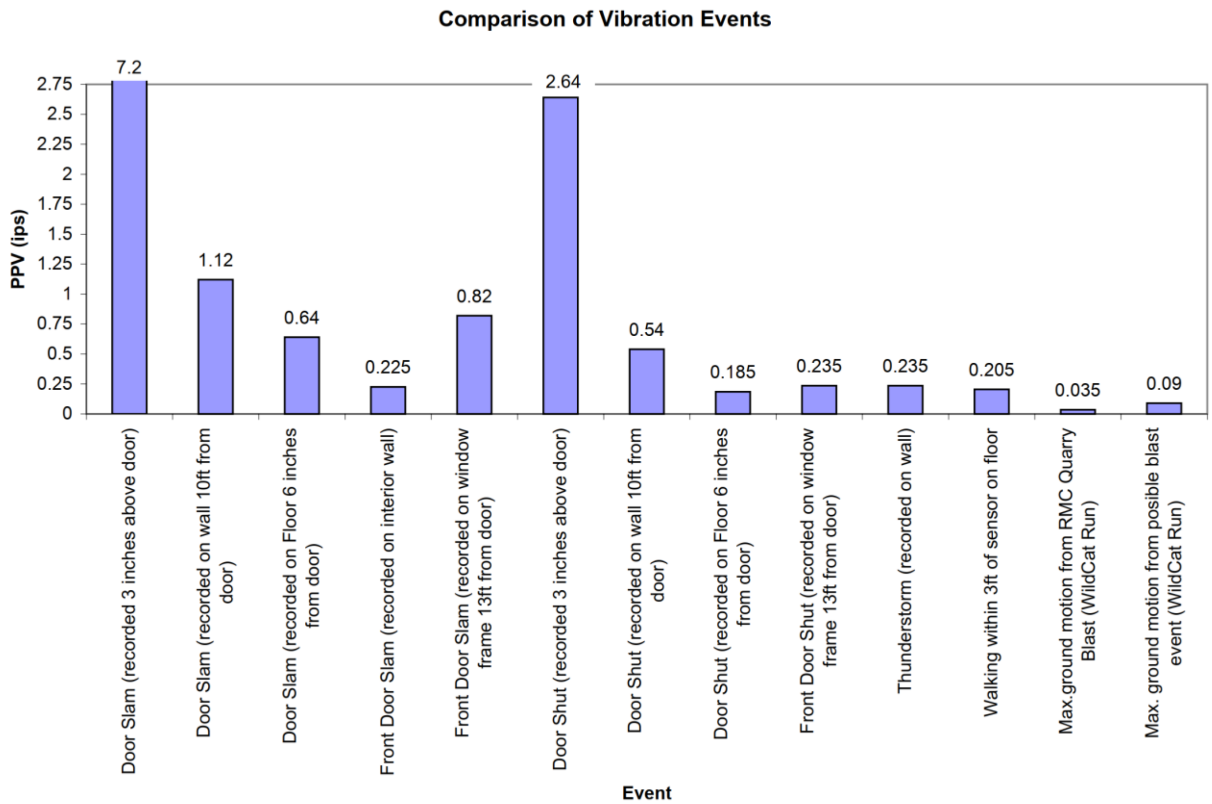
[3] Vibrations from Blasting, Chapter 1, page 3, Copyright © 2000 International Society of Explosives Engineers – David E. Siskind, Ph.D.

Normal Activities and Vibrations

It is also interesting to note that many common household activities produce vibration levels that can be higher than normal construction vibration levels. Research on vibrations has measured the effects of stresses caused by normal household activities as they compare to vibration levels. Household activities often cause homes to shake more than typical external vibration-causing activities. Some of the results from several different authors are summarized in the following graph.



A study performed in 2005 recorded additional vibration levels from household activities. This study showed vibration levels from slamming a door in a home exceeding 7.0 inches/sec in the immediate vicinity of the door (see chart below).



[4]

Proper construction and maintenance can minimize these effects, but it is impossible to eliminate all of the effects brought about by environmental changes. Environmental changes and normal household activities cause more stress on a structure than typical vibration levels from typical construction and regulated blasting activities.

Human Perception

> "Human perceptions are unreliable when determining the compliance of blasting operations. A person's position greatly determines their perception of blasting vibration and air overpressure… Someone standing outside of a home may notice minimal vibration and noise due to a blast, while a person inside the home may report excessive amounts of vibration. The differing perceptions are due to the way a structure responds to the vibration and air overpressure associated with the blasting." [5]

Humans are sensitive. Many people can sense vibration that is 1% of that required to cause damage to structures.[6] People often erroneously presume that a noise loud enough to rattle the walls of their home and activities that cause vibration that they can feel is indicative of damage potential.

Human perception of vibration levels is not a good indicator of vibration levels necessary to cause damage to a structure.

Vibration Dissipation

It is a scientific maxim that energy dissipates with increased distance from the source. The further energy travels the further it spreads out in all directions, and thus, the more it dissipates.

> "Propagation effects and geology change the amplitude and frequency character of ground vibrations as they travel from the blast area to measurement locations. The most important

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[4] Lee County Blasting Study by Terra Dinamica, LLC – Frank Lucca and Andrew Williams

[5] Division of Mineral Mining, 900 Natural Resources Drive, Suite 400, Charlottesville Virginia 22903. www.dmme.virginia.gov

[6] Forensic Engineering Investigation by Randall K. Noon

influence is dissipation, or "geometric spreading," where the finite amount of energy fills an increasingly larger volume of earth as it travels outward in all directions away from the blast. The consequence is generally an exponential decrease in vibration amplitude with increasing distance from the source." 7

Under typical conditions, vibration intensity lessens to about 1/3 of its previous measurement each time the distance is doubled.[8]

Calculated Vibration from Blasting Activities

Vibration levels from blasting can be calculated when you have a distance and the pounds of explosive per delay by using the prediction formula from the "Blasters Handbook" by E.I. DuPont de Nemours & Co. This formula is.

$$V = 160({}^{R}/_{\sqrt{w}})^{-1.6}$$

Where:

V = Peak particle velocity (in/sec)
R = Distance from blasting (ft)
W = Maximum weight of explosives per delay (lbs)

This industry-standard formula was devised by analyzing a large amount of blast data from a wide variety of field and shot conditions. A regression analysis was performed on the data and this prediction formula is based on the 95% confidence interval of that regression analysis. Simply put, this prediction formula should produce a calculated vibration level that is higher than the actual level recorded 95% of the time.

Maine D&B provided their current blast plan for our calculations. This plan indicates a maximum weight of explosives per delay (W) of 105.11 lbs.

Using the standard prediction formula with the largest max/delay planned on any shot and the closest possible distance to each location, the worst-case vibration level was calculated for each location.

Location	Min Distance (ft)	Max/Delay (lbs)	PPV (in/sec)
22 Anderson Drive	260	105.11	0.91
40 Chapman Lane	562	105.11	0.26
89 Point Breeze Road	1018	105.11	0.10

This simple calculation shows that the worst-case scenario for vibration from the planned blasting activities will be far below damage-causing levels.

Additionally, it should be noted that blasting activities will progress toward the outer perimeter of the blasting area from the western side of the site. This ensures that initial blasting activities will be significantly further from the closest locations and monitoring results from early blasting activities will be used to refine the blast plan if necessary to target vibration levels below 1.0 in/sec at the closest structures.

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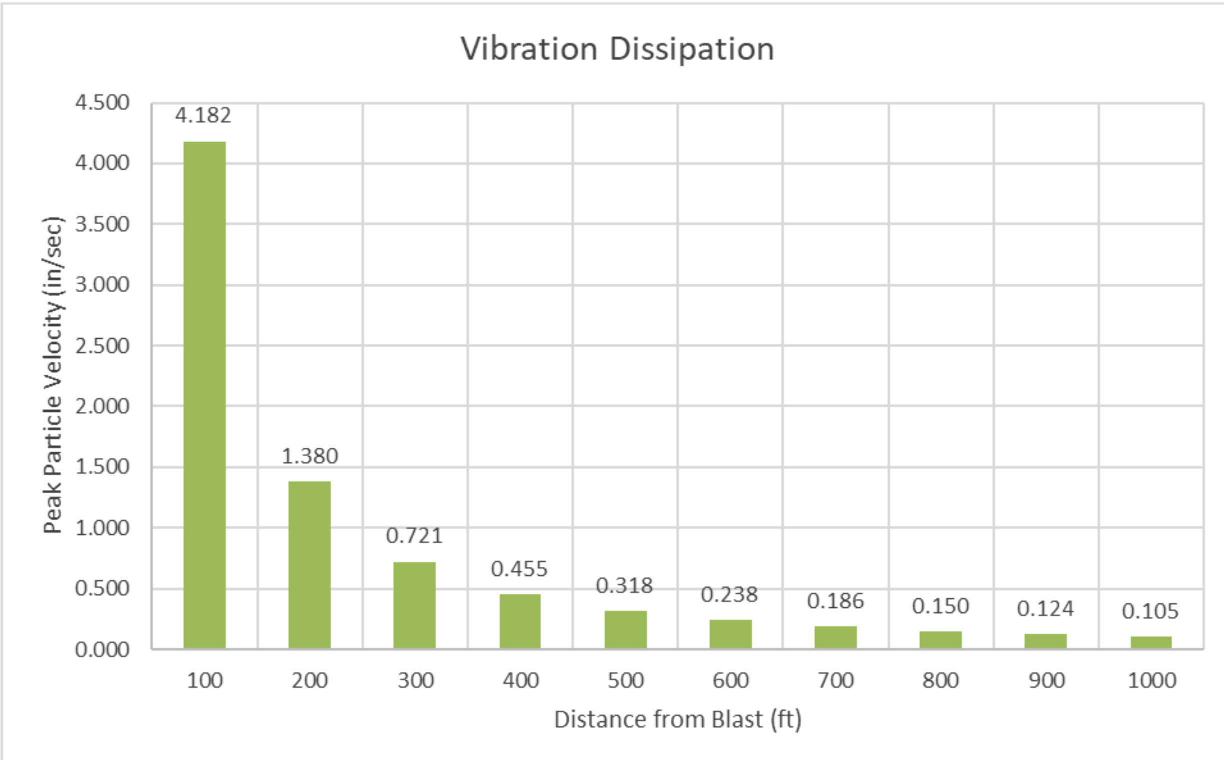
[7] Vibrations from Blasting, Chapter 5, page 17, Copyright © 2000 International Society of Explosives Engineers – David E. Siskind, Ph.D.

[8] The Effects of Vibrations and Environmental Forces: A Guide for the Investigation of Structures, Chapter 2: Procedure for Evaluating Claims of Damage to Structures, pg. 24, Lewis L. Oriard, Published by the International Society of Explosives Engineers.

As indicated above, vibration levels dissipate with distance so targeting vibration levels below 1.0 in/sec at the closest locations ensures that vibration levels at all offsite locations will be well below regulatory and threshold damage levels. The dissipation of the vibration levels over distance are shown in the following graph.



Calculated Vibration from Construction Activities

Similar to blasting vibrations, construction vibrations can also be calculated. Since different types of equipment generate different levels of vibration, vibration levels for a variety of equipment were calculated using standard calculations from FTA-VA-90-1003-06 (May 2006) “Transit Noise and Vibration Impact Assessment” by Carl E. Hanson, David A. Towers, and Lance D. Meister sponsored by the U.S. Department of Transportation - Federal Transit Administration (FTA).

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

where: PPV (equip) is the peak particle velocity in in/sec of the equipment adjusted for distance

PPV (ref) is the reference vibration level in in/sec at 25 feet from Table 12-2

D is the distance from the equipment to the receiver.

Table 12-2. Vibration Source Levels for Construction Equipment (From measured data.[7,8,9,10])

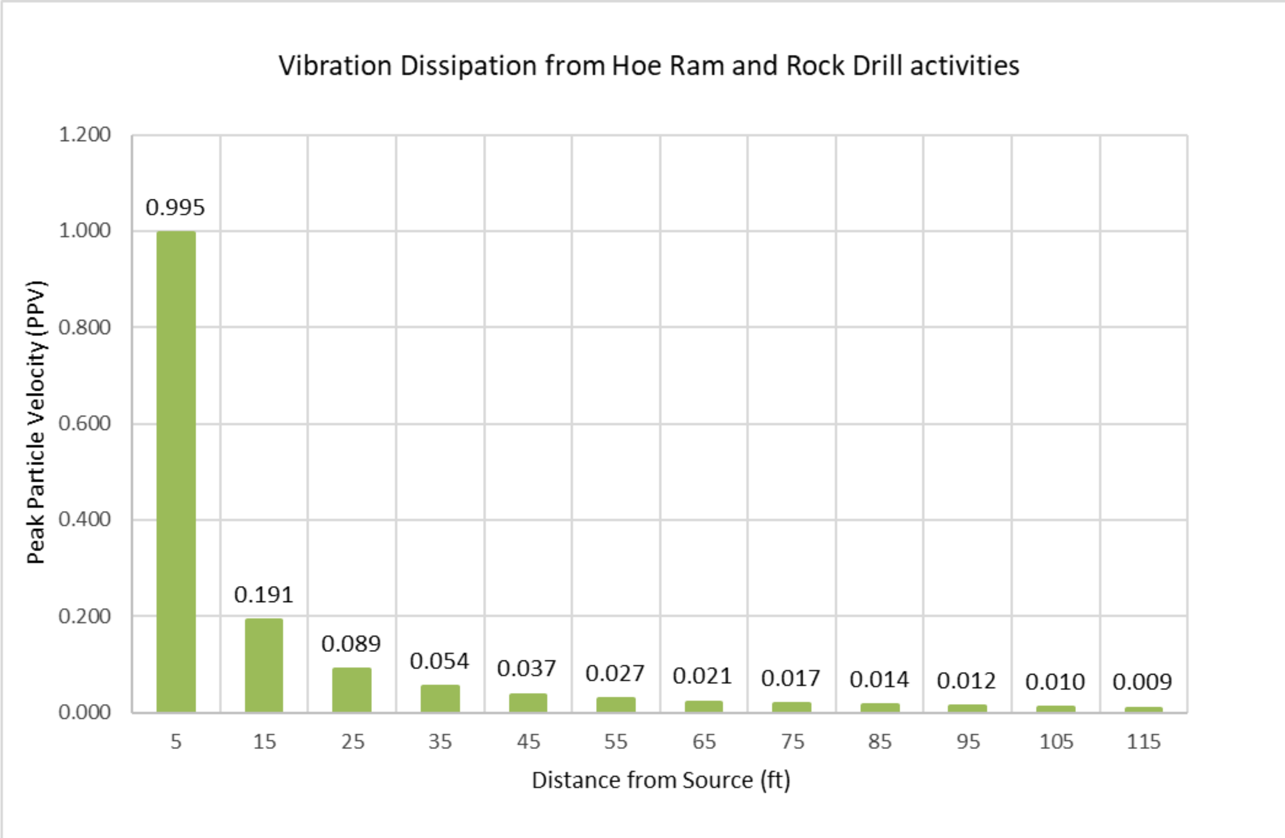
Equipment		PPV at 25 ft (in/sec)	Approximate L_v† at 25 ft
Pile Driver (impact)	upper range	1.518	112
	typical	0.644	104
Pile Driver (sonic)	upper range	0.734	105
	typical	0.170	93
Clam shovel drop (slurry wall)		0.202	94
Hydromill (slurry wall)	in soil	0.008	66
	in rock	0.017	75
Vibratory Roller		0.210	94
Hoe Ram		0.089	87
Large bulldozer		0.089	87
Caisson drilling		0.089	87
Loaded trucks		0.076	86
Jackhammer		0.035	79
Small bulldozer		0.003	58

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

Since many of the vibration sources in the FTA calculation table are not planned for this site (Pile Driver, Clam Shovel drop, Hydromill) Additional research was performed to address anticipated vibration levels from the rock drilling. According to data presented in Appendix D of Ground Vibrations Emanating from Construction Equipment by Richard Lane and Krystle Pelham, vibration from a track drill is comparable to the Hoe Ram/Large bulldozer/Caisson drilling values in the FTA chart.

Based on the FTA data and additional research it is expected that the maximum off site vibration level (worst case) will be best predicted by the calculated values for Hoe Ram/Large bulldozer/Caisson drilling with the FTA calculations.

The graph below shows the expected vibration levels at increasing distance from the primary anticipated construction activities. This chart shows that vibration levels from the anticipated construction activities is expected to be below damage causing levels at 5 feet and below common perception levels at 75 feet.



Additionally, using this calculation process, the closest construction activity to each location was used to calculate worst-case vibration calculations for each location. While these charts include all of the equipment in the standard FTA calculations, the highest vibration generation anticipated from this site is highlighted in green.

As can be seen in the calculations below, the highest vibration level at any location from the anticipated construction activities is 0.003 in/sec. This vibration level is far below threshold damage-causing levels and below the perception level for most people.

Construction Vibration Calculation for 22 Anderson Drive (260 ft)

Table 12-2. Vibration Source Levels for Construction Equipment (From measured data.[7,8,9,10])

Equipment		PPV at 25 ft (in/sec)	Approximate L_v† at 25 ft	Distance (ft)	Calculated PPV (in/sec)
Pile Driver (impact)	upper range	1.518	112	260	0.045
	typical	0.644	104	260	0.019
Pile Driver (sonic)	upper range	0.734	105	260	0.022
	typical	0.170	93	260	0.005
Clam shovel drop (slurry wall)		0.202	94	260	0.006
Hydromill (slurry wall)	in soil	0.008	66	260	0.000
	in rock	0.017	75	260	0.001
Vibratory Roller		0.210	94	260	0.006
Hoe Ram		0.089	87	260	0.003
Large bulldozer		0.089	87	260	0.003
Caisson drilling		0.089	87	260	0.003
Loaded trucks		0.076	86	260	0.002
Jackhammer		0.035	79	260	0.001
Small bulldozer		0.003	58	260	0.000

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

Construction Vibration Calculation for 40 Chapman Lane (562 ft)

Table 12-2. Vibration Source Levels for Construction Equipment (From measured data.[7,8,9,10])

Equipment		PPV at 25 ft (in/sec)	Approximate L_v† at 25 ft	Distance (ft)	Calculated PPV (in/sec)
Pile Driver (impact)	upper range	1.518	112	562	0.014
	typical	0.644	104	562	0.006
Pile Driver (sonic)	upper range	0.734	105	562	0.007
	typical	0.170	93	562	0.002
Clam shovel drop (slurry wall)		0.202	94	562	0.002
Hydromill (slurry wall)	in soil	0.008	66	562	0.000
	in rock	0.017	75	562	0.000
Vibratory Roller		0.210	94	562	0.002
Hoe Ram		0.089	87	562	0.001
Large bulldozer		0.089	87	562	0.001
Caisson drilling		0.089	87	562	0.001
Loaded trucks		0.076	86	562	0.001
Jackhammer		0.035	79	562	0.000
Small bulldozer		0.003	58	562	0.000

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

Construction Vibration Calculation for 89 Point Breeze Road (1,018 ft)

Table 12-2. Vibration Source Levels for Construction Equipment (From measured data.[7,8,9,10])					
Equipment		**PPV at 25 ft (in/sec)**	**Approximate L_v† at 25 ft**	**Distance (ft)**	**Calculated PPV (in/sec)**
Pile Driver (impact)	upper range	1.518	112	1018	0.006
	typical	0.644	104	1018	0.002
Pile Driver (sonic)	upper range	0.734	105	1018	0.003
	typical	0.170	93	1018	0.001
Clam shovel drop (slurry wall)		0.202	94	1018	0.001
Hydromill (slurry wall)	in soil	0.008	66	1018	0.000
	in rock	0.017	75	1018	0.000
Vibratory Roller		0.210	94	1018	0.001
Hoe Ram		0.089	87	1018	0.000
Large bulldozer		0.089	87	1018	0.000
Caisson drilling		0.089	87	1018	0.000
Loaded trucks		0.076	86	1018	0.000
Jackhammer		0.035	79	1018	0.000
Small bulldozer		0.003	58	1018	0.000
† RMS velocity in decibels (VdB) re 1 micro-inch/second					

Air Overpressure from Blasting

When discussing Air Overpressure (often referred to as airblast), people always want to equate it with noise or sound. Although there is an audible sound associated with airblast, we are monitoring the change in pressure. Much of this pressure wave occurs below the frequency range that is audible to humans. Humans can typically hear sound waves with frequencies between 20 Hz and 20,000 Hz.

> "A sound wave progressing through air causes the instantaneous air pressure at any given point to vary above and below the barometric pressure in accordance with the WAVEFORM of the sound. This variation in pressure is used as a quantitative measure of the strength of the sound, and is called sound pressure. This is the quantity which a PRESSURE MICROPHONE measures, and if it is expressed on a DECIBEL scale and referred to a pressure of 20 micropascals, it is called sound pressure level."[9]

Measurement Scales

The most common scales used to discuss sound pressure are decibels (dBL (Linear) or dBF (Flat)) or pounds per square inch (psi). This adds more confusion because dBs are recorded on a logarithmic scale and psi is recorded on a linear scale.

> "In a linear scale, the steps are evenly spaced, and the units (such as length or intensity) represented between each measure is the same. For example, the length between 1 and 2 is the same as the length between 3 and 4. Logarithmic scales are based on multiplication rather than addition. In a logarithmic scale, the steps increase or decrease in size. A logarithmic scale is based on the power of 10. In a logarithmic scale, the length between 2 and 3 is ten times the length between 1 and 2. The length between 3 and 4 is 100 times greater than the length between 1 and 2. Each step on a logarithmic scale is an order of magnitude." [10]

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[9] http://otto.cmr.fsu.edu/~elec4mus/topics/decibel.html - Excerpt from Audio Dictionary by Glenn While
[10] http://sirtf.caltech.edu/EPO/Field/linlog.html - Cosmic Reference Guides - Linear vs Logarithmic

An increase of 6 dB(L) is equivalent to doubling the sound pressure level. This is not the same as twice as loud; it is twice as much sound *pressure*. Conversely, a decrease of 6 dB(L) is equal to reducing the sound pressure level by half.

If we were talking about sound, a change of 3 dB results in a doubling of acoustical energy and a change in 10 dB would increase the acoustical energy 10 times. Also, a 10 dB increase in sound is considered a doubling of loudness. As you can see, loudness and acoustical energy are different from sound pressure levels.

Safe Levels

Threshold air overpressure damage is easily recognized, and more serious air overpressure damage cannot occur without a great deal of characteristic "threshold" type air overpressure damage:

> "Blasting vibration experts, governmental regulatory agencies, and consultants generally agree that, if airblast causes any damage, it will first manifest itself in the form of broken window glass. Damage such as plaster cracking is very rare, but when it occurs it is always accompanied by window breakage and occurs almost simultaneously. Large plate-glass and storefront-type windows are more prone to damage than are smaller window panes. Poorly set pre - stressed, or loose panes are more prone to fracture than well set, firm plates that have no stress raisers such as glazier's brads. It should be noted that airblast may not be audible and that the "loudness" of an event is not a real indicator of whether or not it could have caused the damage." [11]

Air overpressure can often be heard and felt at significant distances from the blasting activities. It is common for air overpressure to be the cause of neighbor complaints.

Regulatory Limit

The most common regulatory limit for Air Overpressure from blasting is clearly stated by the National Fire Protection Association.

> "Air overpressure due to blasting operations shall not exceed the maximum limit of 133 dB(L) (0.013 psi) at the location of any building or structure."[12]

As noted above, air overpressure doubles with every 6 dB(L) increase – conversely, air overpressure level is one-half with every 6 dB(L) decrease.

133 dB(L) = Regulatory limit
127 dB(L) = ½ (50%) of limit
121 dB(L) = ¼ (25%) of limit

Damage thresholds for smaller residential-size panes are about 164 dB(L). As discussed above, the decibel scale is a *logarithmic* scale that measures air pressure waves related to the response of the human ear. The force (in pounds per square inch or psi) is more easily understood when considering damage potential. A 130 dB(L) level is about 0.01 psi. An approximate damage threshold of 164 dB(L) is about 0.5 psi.

Stress

In general, the force of wind on a structure causes more stress than typical air overpressure levels from blasting.

> "Contrary to intuition, a wind pressure of a given amount is more likely to break windows than a transient pulse of the same peak pressure. If the pressure acts over a longer time, the damage potential is increased, along with the fact that wind gusts will often increase the nominal wind

[11] American Insurance Association, "Blasting Damage: A guide For Adjusters and Engineers" 3rd Edition, 1990, p8.
[12] NFPA® 495 - Explosive Materials Code - 2013 Edition – Chapter 11 – Section 3.1

pressure by 25-50%. Simply stated, the low-frequency oscillation in a wind gust usually has more damage potential than a transient high-frequency air wave or sonic boom at the same nominal peak pressure.

At the same time, moderate winds are not as noticeable to building occupants because they make less noise and do not begin as suddenly. Therefore, the true physical facts are in contradiction to the accounts of persons who may conclude that the transient effects of the air waves were stronger than those generated in the structure."[13]

"Blowing and gusting winds can cause damage and this is most often seen in connection with hurricanes which produce winds in excess of 100 MPH. The forces produced by blowing winds are related to the kinetic energy for the wind as calculated by KE = 1/2 times mass times velocity square and how much of this energy is dissipated as the wind strikes the wall, house, or area where damages may be done. Most buildings are constructed such as to dissipate the energies without damages from less than hurricane winds. In most instances, window glass is the weakest part in term of possible damage from the wind. Air overpressure waves produced by blasting are similar to gusting winds in terms of kinetic energy. Most blasting with any reasonable degree of containment of the energy for effective rock breakage and controlled rock throw will not cause heavy enough air overpressure waves to cause damage even to buildings that are at a close distance."[14]

Since glass is typically the first material to be damaged from high air overpressure levels, the primary concern when evaluating potential window damage from blasting is the air overpressure levels associated with the blasting events. Windows are constantly subjected to various stresses caused by activities such as opening and closing windows and normal environmental conditions such as wind, thunder, and temperature changes.

Air Overpressure Assessment

Air Overpressure levels from blasting can be calculated when you have a distance and the pounds of explosive per delay by using the open-air prediction formula from the "Blasters Handbook" by E.I. DuPont de Nemours & Co. This formula is:

$$P_U = 82\left(R/\sqrt[3]{W}\right)^{-1.2}$$

Where

P_U = Predicted airblast for *unconfined* blast (psi)
R = Distance from blasting (ft)
W = Max. weight of explosives per delay (lbs)

Once the unconfined value is calculated, it is then converted to decibels (dBL) using the formula

$$P_{U(dB)} = 100 + 20\text{Log}\left(P_{U(psi)}/0.00029\right)$$

Where

$P_{U(dB)}$ = Predicted airblast for *unconfined* blast in decibels (dBL)
$P_{U(psi)}$ = Predicted airblast for *unconfined* blast in pounds per square inch (psi)

Next, the unconfined decibel reading is reduced by 30-40 dBL to estimate the confined airblast level in decibels. For our standard prediction, we reduce the airblast level by 35 dBL.

$$P_{C(dBL)} = P_{U(dBL)} - 35$$

[13] The Effects of Vibration and Environmental Forces: A Guide for the Investigation of Structures" by Lewis Oriard, Page 218
14 Natural Causes vs. Blasting Damage - Copyright© 1997 International Society of Explosives Engineers - By Earl C. Hutchison and Wade C. Hutchison, President VCE, Inc.

Where

$P_{U(dBL)}$ = Predicted airblast for *unconfined* blast in decibels (dBL)
$P_{C(dBL)}$ = Predicted airblast for *confined* blast in decibels (dBL)

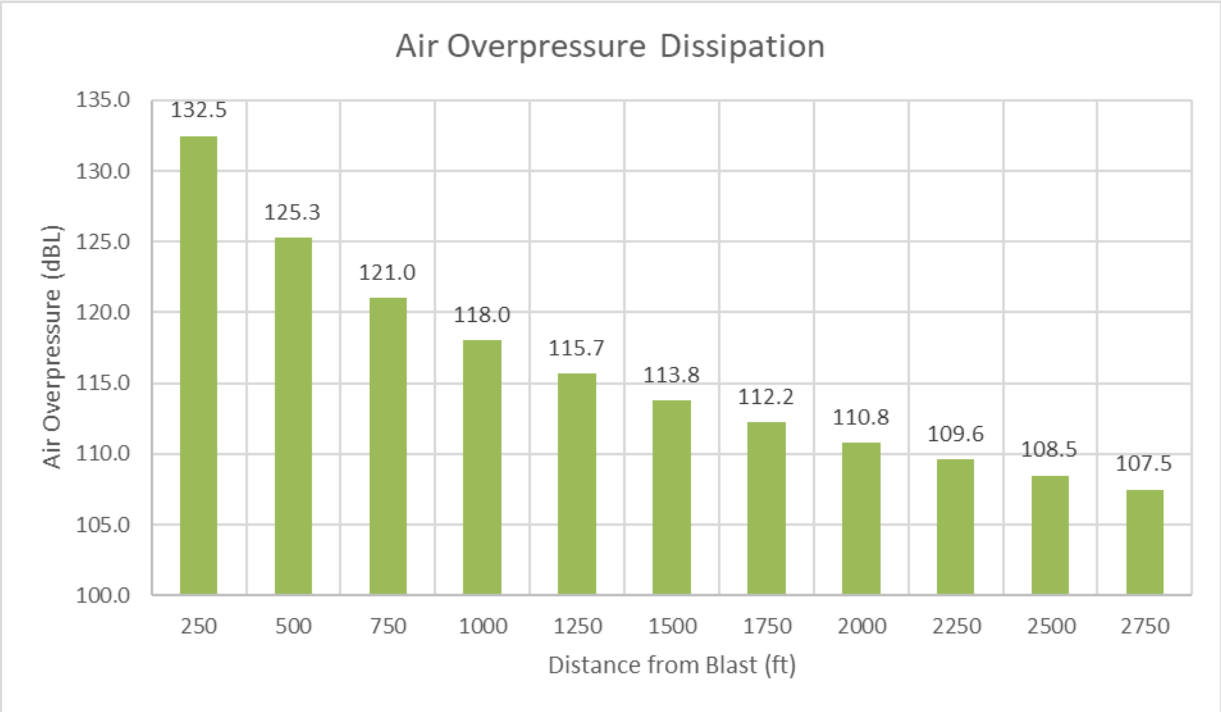
Calculated Air Overpressure from Blasting Activities

The airblast levels were calculated for the nearby structures using the standard prediction formula above and the maximum pounds of explosive per delay from the blast plans submitted by Maine D&B utilizing the project blast location nearest to the identified receptor.

Location	Min Distance (ft)	Max/Delay (lbs)	Airblast (dBL)
22 Anderson Drive	260	105.11	132.24
40 Chapman Lane	562	105.11	124.21
89 Point Breeze Road	1018	105.11	118.02

This calculation predicts an air overpressure level below the regulatory limit and far below threshold damage levels at all locations near the proposed blasting activities.

As indicated above in the blast vibration discussion, blasting activities will begin in a location much further from the closest structure than these worst case calculations and design changes will be implemented if necessary in order to ensure compliance with regulatory limits and maintain air over pressure levels far below threshold damage levels at all off site locations.



Conclusion

Based on the planned blasting and construction activities and industry standard calculations, vibration levels and air overpressure from blasting and construction activities on this project will remain below regulatory limits and far below threshold damage levels at the adjacent locations.

Please do not hesitate to contact me if you have any questions.

Sincerely,
Sauls Seismic, LLC

Gregory B Poole
VP – Technical Services