Vibra-Tech

STAMP blasting vibration

Frontier Stone, LLC Project
Prediction of Blast Induced Ground Vibration at Western New York Science & Technology Advanced Manufacturing Park ("STAMP")
Alabama, NY

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1 Executive summary

Frontier Stone, LLC is in the planning stages for a new quarry located approximately 5 miles north of Alabama, New York. The State of New York is currently in the process of acquiring land for Western New York, Science and Technology Advanced Manufacturing Park (STAMP). The STAMP will house semiconductor and nanotechnolgy manufacturing and research facilities. The equipment used by these facilities is sensitive to ground vibration at levels that are below human perception. There is concern that rock excavation using underground blasting at the Frontier Stone quarry located approximately 5 miles north may exceed vibration levels acceptable to these facilities.

Colin Gordon Associates was commissioned by STAMP parties to conduct an ambient vibration study in September of 2012. The results of the study show that the ambient vibration levels at the STAMP property are extremely low meeting both the NIST-A and VC-E vibration criteria. This level of ambient vibration is due to the remote nature of the site. Ambient vibration measurements conducted by Vibra-Tech were consistent with the past vibration measurements.

Vibra-Tech Engineers was commissioned by Frontier Stone, LLC to conduct a field test on September 17, 2014 where a single hole test blast was detonated using an existing monitoring well on the proposed quarry property. This study consisted of using a linear array of 41 seismographs and two (2) spectrum analyzers with seismic accelerometers to measure ground vibration between the proposed quarry and the STAMP area resulting from the detonation of a 382 kg (843 lbs.) confined single hole blast. A statistical analysis was performed on the measured ground vibration to develop a site-specific equation for the prediction of ground vibration amplitude at the STAMP area based on distance and the weight of explosives used.

The quarry has four (4) phased areas of rock removal planned. Phase I is the closest proposed quarry area to the STAMP property. The proposed Phase 1 quarry boundary ranges from approximately 7,606 meters (4.7 miles) to 7,940 meters (4.93 miles) from the closest STAMP location.

Based on the analysis of the collected data and the closest blasting distance of 7,606 meters (4.7 miles) production blast plans have been developed to limit ground vibrations at the STAMP induced by quarry blasting to meet the very restrictive VC-E vibration criteria, and the most restrictive NIST-A criteria.

Predictions show that the NIST-A and VC-E vibration criteria could be met at the closest distance of 7,606 meters if the production shot was limited to 20 kg (44 lbs.) of explosives per deck. A fourteen (14) hole blast consisting of 101.6 mm (4 inch) diameter holes with three (3) explosive decks per hole would achieve this objective. This production blast would yield approximately 6,888 tons of material.

Blast simulations indicate that 72 ms is the optimum delay period between explosive charges for maximum reduction in ground vibration from destructive interference in the seismic waves. Delay periods less than 50 ms between explosive charges are expected to increase ground vibration levels at the STAMP due to constructive reinforcement between the seismic waves. The resulting surface wave at the STAMP area will have an envelope of approximately 8 seconds. After 8 seconds the ground vibration at the STAMP property will return to the ambient conditions.

It should be noted that all blast designs and explosive simulations in this report are based on seismic data collected from a highly confined single-hole blast. Once the pit is developed and free faces exist for production blasting operations, an adjustment in delays and maximum explosive charge per delay may be possible based upon ongoing seismic recordings.

2 Vibration Terminology

Vibration levels are quantified by a variety of parameters and metrics. In order to aid the reader, this section introduces general concepts and terminology related to acoustics and environmental noise. The following related technical terms and criteria used for this project are summarized and outlined below:

2.1 Vibration

Vibration is a periodic motion of the particles of an elastic body or medium in alternately opposite directions from the position of equilibrium when that equilibrium has been disturbed. Vibration can be described in terms of three variables: amplitude, frequency, and time pattern (variability). The amount of movement associated with a vibration can be measured in terms of displacement, velocity, or acceleration. Displacement is a measure of the physical distance traveled from a position of equilibrium or base line. Velocity is a measure of the speed at which the displacement occurred and acceleration is a measure of the change in velocity occurring during the vibration event. The relationships between displacement, velocity, and acceleration are dependent upon the frequency of the motions measured.

2.2 Peak Particle Velocity (PPV)

The maximum speed a particle moves from its equilibrium position because of the passage of a seismic wave.

2.3 Root Mean Square Velocity (rms)

The energy average of the vibration level defined as the square root of the average of the squares of a series of measurements.

2.4 Frequency (Hz)

The rate of motion, or the number of vibrations occurring in a given period, usually one second, is called the frequency of the motion, which is described as the number of cycles/second (cps) or Hertz (Hz). Frequency based criteria are expressed in linear bands or with using proportional bandwidths which increase as frequency increases. The vibration criteria in this project uses a proportional bandwidth 1/3 octave frequency bands.

2.5 Transient Vibration

Vibration can be quantified based on duration. Transient vibration is temporarily sustained in nature and is the result of impacts, shocks. Blasting will generate transient vibration. Transient vibration is typically not of long enough duration to bring a structure up to full resonance response.

2.6 Steady State Vibration

Vibration in which the velocity of each particle in the system is a continuous periodic quantity.

2.7 Explosive Confinement

Charge confinement affects the vibration intensity. If a charge is deeply buried or totally confined without a nearby free face, the rock cannot be displaced and more energy is transferred to ground vibration.

2.8 Seed Waveform Technique

The earth is a linear system, which means that when subjected to a consistent input, a consistent output will be produced. With this technique, a single borehole loaded with explosives is detonated within the quarry site and recorded with seismographs at the location of concern. Since a single hole waveform (Seed Wave) is a reproducible event, it is reasonable that the seismic signature from a multi-hole production blast can be predicted by summing a series of single hole waveforms that have been time-lagged at intervals corresponding to delay times from the production blast.

3 Vibration Criteria

Two vibration criteria have been compared to the measured data; the most restrictive is the NIST-A criteria

3.1 Generic Vibration Criteria

The generic vibration criteria curves are the industry standard used to aid architects and engineers in the design of facilities housing equipment sensitive to vibration. Organizations such as AISC, ASHARE, IEST, and NIH recommend their use. These guidelines are valuable in the preliminary design phase and in the absence of specific equipment vibration criterion. Classifications range from "A" to "G" depending on equipment sensitivity. Where Class A is the least stringent and Class G is the most stringent. "Class E" facilities are very difficult to achieve in most instances. The vibration levels in all of these classifications are below what is perceptible by humans.

This criteria is based on the rms velocity amplitude metric of um/s, measured using 1/3 octave frequency bands from 1 Hz to 80 Hz. The following table and figure show the generic vibration criteria for various types of sensitive equipment:

Figure 3 Generic Vibration Criterion (VC) Curves for Vibration Sensitive Equipment and ISO Guidelines for People in Buildings [From IEST RP-012.2 (2005)]

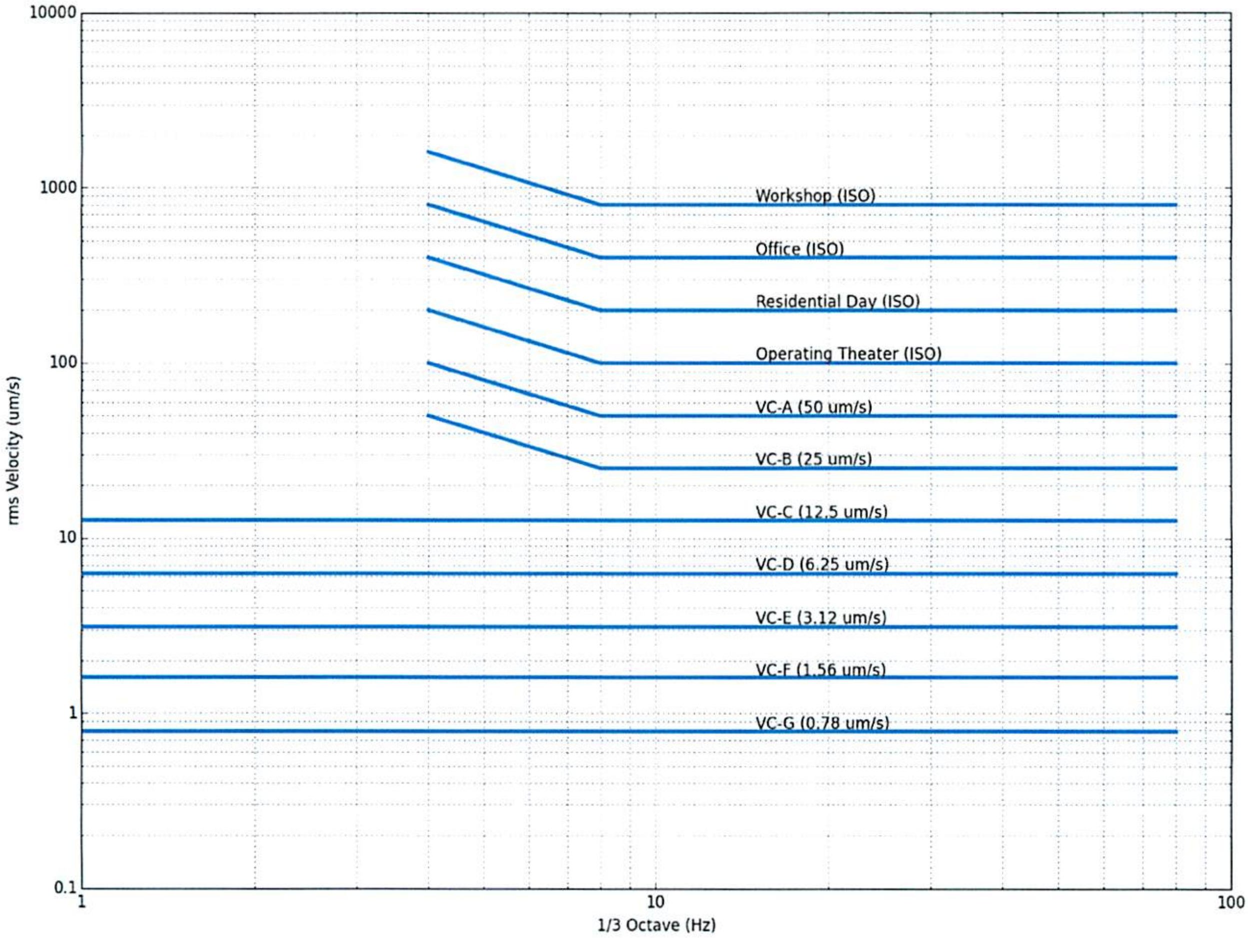


Table 3-1 Numerical Definition of (VC) curves

Criteria Curve	Definition
VC-A	260 ug between 4 Hz and 8 Hz, 50 um/s (2000 uin/s) between 8 Hz and 80 Hz
VC-B	130 ug between 4 Hz and 8 Hz, 25 um/s (1000 uin/s) between 8 Hz and 80 Hz
VC-C	12.5 um/s (500 uin/s) between 1 and 80 Hz
VC-D	6.25 um/s (250 uin/s) between 1 and 80 Hz
VC-E	3.1 um/s (125 uin/s) between 1 and 80 Hz
VC-F	1.6 um/s (62.5 uin/s) between 1 and 80 Hz
VC-G	0.78 um/s (31.3 uin/s) between 1 and 80 Hz

Table 3-2 Application and Interpretation of the Generic Vvibration Criterion (VC) Curves

Criteria Curve	Amplitude[1] µm/s (µin/s)	Detail size[2] µm	Description of use
Workshop (ISO)	800 (32,000)	N/A	Distinctly perceptible vibration. Appropriate for workshops and non-sensitive areas.
Office (ISO)	400 (16,000)	N/A	Perceptible vibration. Appropriate for offices and non-sensitive areas.
Residential Day	200 (8,000)	75	Barley perceptible vibration. Appropriate to sleep areas in most instances. Usually adequate for computer equipment, hospital recovery rooms, semiconductor probe test equipment and microscopes less than 40X.
Operating Theatre (ISO)	100 (4,000)	25	Vibration not perceptible. Suitable in most instances for surgical suites, microscopes to 100X and for other equipment of low sensitivity.
VC-A	50 (2,000)	8	Adequate in most instances for optical microscopes 400X, microbalances, optical balances, proximity and projection aligners, mass spectrometers other than MALDI and quadrupole or higher resolution conventional spectrophotometers, etc.
VC-B	25 (1,000)	3	Appropriate for inspection and lithography equipment (including steppers) to 3 µm line widths, mirotomes and cryotomes for 5 – 10 micron slices, most tissue and cell culture, except as noted below.
VC-C	12.5 (500)	1 – 3	Appropriate standard for optical microscopes to 1000x, lithography and inspection equipment (including moderately sensitive electron microscopes) to 1 µm detail size, TFT-LCD stepper/scanner process, digital imaging and/or fluorescence with optical microscopes, high-precision balances measuring quantities less than 1 mg, MALDI mass spectrometer, nano-drop spectrophotometers mirotomes and cryotomes for slices < 5 microns, tissue and cell culture of the following types: hanging drop, unstirred layers, embryonic stem cells, weakly adherent cells, very long-term cultures, chemotaxis, invasion assays.
VC-D	6.25 (250)	0.1 – 0.3	Suitable in most instances for demanding equipment, including man electron microscopes (SEMs and TEMs) and E-Beam systems, microinjection, micromanipulation, electrophysiology, confocal microscopy, quadrupole and other high-resolution mass spectrometers.
VC-E	3.12 (125)	< 0.1	A challenging criterion to achieve. Assumed to be adequate for the most demanding of sensitive systems including long path, laser-based, mall target systems-Beam lithography systems working at nanometer scales, and other systems requiring extraordinary dynamic stability.
VC-F	1.56 (62.5)	N/A	Appropriate for extremely quiet research spaces; generally difficult to achieve in most instances especially cleanrooms. Not recommended for use as design criteria.
VC-G	0.78 (31.3)	N/A	Appropriate for extremely quiet research spaces; generally difficult to achieve in most instances especially cleanrooms. Not recommended for use as design criteria.

1 As measured in one-third octave bands of frequency over the frequency range of 8 to 80 Hz (VC-A and VC-B) or 1 to 80 Hz (VC-C through VC-G).

2 The detail size refers to line width in the case of microelectronics fabrication, the particle cell size in case of medical and pharmaceutical research, etc. It applies only to visualization, and does not pertain to chemical and separation process. It is not relevant to imaging associated with probe technologies, AFM's and nanotechnology.

3.2 NIST-A Vibration Criteria

The NIST-A vibration criteria was developed for construction of the National Institute of Standards and Technology Advanced Measurement Laboratory. The NIST-A criterion is identical to the VC-E curve at frequencies above 20 Hz. Below 20 Hz. however, the NIST-A curve maintains constant rms displacement amplitude of 0.025 µm.

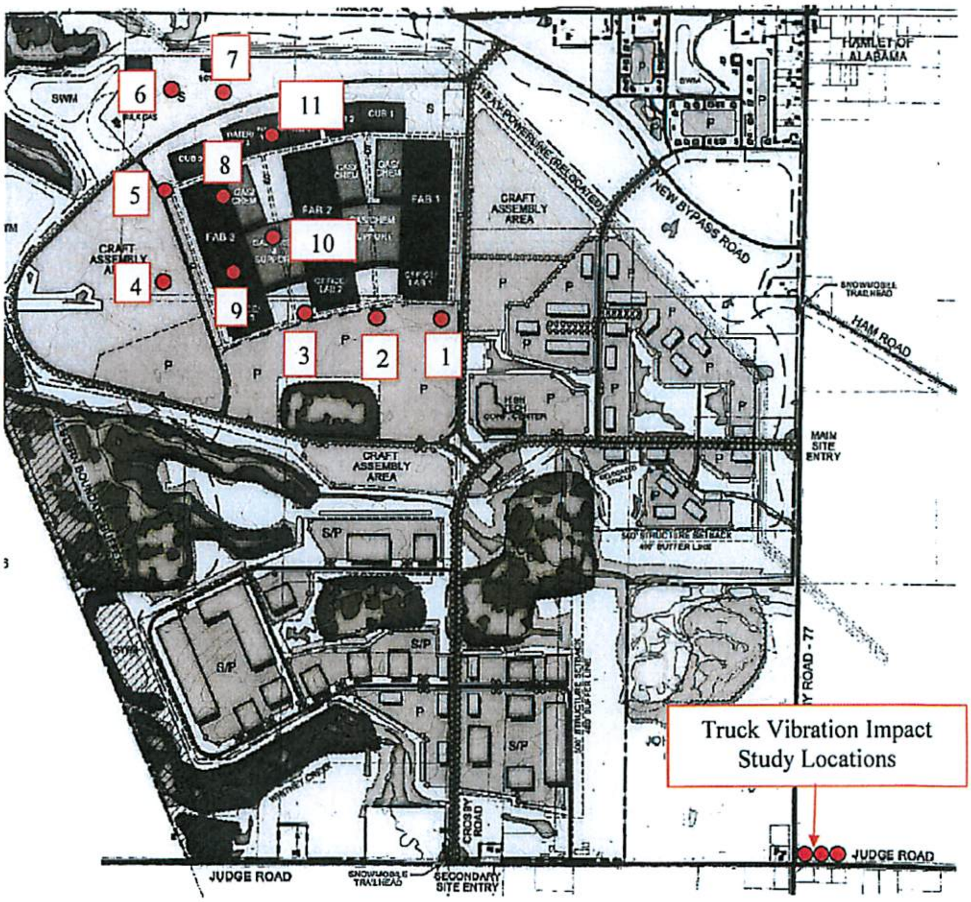
4 Colin Gordon STAMP Site Vibration Report

Colin Gordon Associates Inc. conducted ambient vibration measurements at the STAMP area and submitted their results in the September 13, 2012 report titled "Western New York, Science and Technology Advanced Manufacturing Park (STAMP) Vibration Site Study".

4.1 Vibration Monitoring Locations

Colin Gordon collected ambient surface vibration data at eleven (11) locations throughout the STAMP area. The following figure from their September 13, 2012 report illustrates the measurement locations.

Figure 4-1 Colin Gordon Ambient Vibration Measurement Locations



4.2 Ambient Vibration Results

Colin Gordon Associates Inc. conducted ambient vibration measurements at eleven (11) locations around the STAMP area. Data was collected in both the horizontal and vertical orientations for approximately 90 seconds per location. The data was then spatially averaged to give an overall result. Surface ambient vibration was reported as meeting NIST-A in all directions. Short duration transient vibration from truck traffic was found to exceed VC-E at distances less than 12 meters.

5 Instrumentation

Two (2) types of instrumentation were used in this study, high sensitivity seismic accelerometer based spectrum analyzers, and geophone based blasting seismographs. Forty-one (41) general blasting seismographs were used at locations ranging from 91 meters to 4,731 meters from the test blast. The two spectrum analyzers with high sensitivity seismic accelerometer were located at STAMP locations 4 and 7 approximately 8,817 meters and 8,286 meters respectively.

5.1 Spectrum Analyzer and Seismic Accelerometers

Measurement equipment used at STAMP Locations 4 and 7 consisted of embedded computers with a 16-channel digital spectrum analyzer interface board and programmable analog filters. Each channel has a separate 16-bit analog to digital converter all synchronized to a master clock. Vibra-Tech's data collection/archival system allows for collection and archiving of vibration data in both the time and frequency domains as well as signal processing features which aid in analysis of both random and periodic vibration phenomena. Three (3) Wilcoxon Research model 731 ultra low frequency seismic accelerometers were used at each monitoring location. The systems were programmed to continuously monitor ground vibration at a rate of 1,024 samples per second per channel, and stream the ground vibration continuously to the memory storage. Low-pass filters cut off frequencies were set to 125 Hz. Amplifier gain was set to x10 for an effective sensitivity of 100 V/g.

The transducers used for conversion of physical vibration phenomena into analog current/voltage signals were Wilcoxon Research model 731 ultra low frequency seismic accelerometers and model P31 Power Unit Amplifier/Filters. These sensors have the capability of measuring vibration levels to the sub-micro g level. The system is particularly suited for the measurement of low level vibration for optical and photographic stability monitoring, electron microscope and vibration isolation table monitoring. The accelerometers have the following characteristics:

Accelerometer Model 731 with P31 Amplifier Charge Coupler
Voltage Sensitivity: 100 v/g
5%@0.12 Hz - 410 Hz
10%@0.08 Hz - 510 Hz
3dB@0.04 Hz - 690 Hz
Mounted Resonance 0.86 kHz
Max Amplitude Range 0.5 g Peak

5.2 Seismographs

GeoSonics SSU MicroSeis seismographs deployed during this study are four channel recorders, which directly measure particle velocity in three mutually perpendicular planes of motion. The fourth channel monitors air concussion effects. These seismographs have a dynamic range up to 5.0 in/sec. The sampling rate is up to 1,000 samples/second/channel. The MicroSeis seismographs were programmed to record vibration levels that exceeded a threshold level of 0.05 in/sec for the regular units and 0.02 in/sec for the x4 amplified units. The record length was set at 10.0 seconds. The tri-axial geophone system utilized three, 6-inch spikes to ensure proper coupling to the ground.

The Vibra-Tech Everlert VE, Everlert III, and MultiSeis seismographs have a dynamic range up to 10.0 in/sec. The sampling rate is up to 1,024 samples/second/channel. These seismographs were programmed to record vibration levels that exceeded a threshold level of 0.10 in/sec. The record length was set at 10.0 seconds. The tri-axial geophone system utilized three, 3-inch spikes to ensure proper coupling to the ground.

6 Single Hole Test Blast

A field test was conducted on September 17, 2014 where a single-hole test blast was detonated using existing monitoring well MW-1 located on the proposed quarry property. The monitoring well was located at N43° 09.50754', W078° 21.69480'. The monitoring well was a 152.4 mm (6 in) diameter hole drilled to a depth of 44.56 meter (156 ft.). The upper 8.8 meter (29 ft) of the hole is unconsolidated soil. The hole was cased with steel approximately 1 to 1.5 meter (3 ft to 5 ft) into rock of the Lockport formation. The bottom 1.8 meters (6 ft) of the hole is founded in the Rochester shale.

The bottom 4.8 meters (16 ft) was backfilled with 12.7 mm (½ in) crushed stone. The hole was loaded with PowerAN 500 from a depth of 36.5 meter (120 ft) to 14.8 meter (48.5 ft) in the borehole giving a 21.8 meter (71.5 ft) explosive column with an approximate charge weight of 382 kg (843 lbs.). The PowerAN 500 product is a cartridge emulsion (5" x 30") having a density of 1.25 to 1.30 g/cc (0.047 lb./in^3). The remainder of the hole, 14.8 meters (48.5 ft) was stemmed with 12.7 mm (½ in) crushed stone. The explosive column was initiated from three points within the column utilizing 0.454 kg (1 lb.) Pentex AP-16 boosters with Unitronics 600 electronic caps.

6.1 Proposed Frontier Quarry Location

The proposed Frontier Quarry is located to the north of Alabama, New York and the STAMP area. Four (4) phased areas of rock removal are planned. Phase I is the closest proposed quarry area to the STAMP area. The proposed quarry boundary for Phase 1 ranges from approximately 7,606 meters (4.7 miles) to 7,940 meters (4.93 miles) from STAMP Location #7.

Table 6-1 Distance Between Proposed Quarry Area and STAMP Area

Description	Quarry Phase I Distance (meter)	Quarry Phase II Distance (meter)	Quarry Phase III Distance (meter)	Quarry Phase IV Distance (meter)
STAMP Location #4 Nearest Distance to Quarry Blasting Area	8,136	8,334	8,709	8,542
STAMP Location #4 Farthest Distance to Quarry Blasting Area	8,472	9,035	9,525	8,856
STAMP Location #7 Nearest Distance to Quarry Blasting Area	7,606	7,795	8,180	8,007
STAMP Location #7 Farthest Distance to Quarry Blasting Area	7,940	8,510	8,999	8,322

Table 6-2 Single Hole Blast Induced Ground Vibration Measurement

Description	Latitude	Longitude
Single Hole Test Blast Location	N43° 09.50754'	W078° 21.69480'
STAMP Measurement Location 4	793	1,282
STAMP Measurement Location 7	1,171	1,519

6.2 Measured Single Hole Blast Induced Ground Vibration at STAMP

The following section provides details of the ground vibration measurements at the two STAMP monitoring locations, induced by the 382 kg (843 lbs.) single-hole test. The following tables summarizes the peak ground velocity levels from the time history records, the dominant ground frequencies from the spectral analysis, and the 1/3 octave analysis compared with the VC-curve criteria. Ground vibration is greatest in the horizontal directions.

Table 6-3 Ground Vibration Induced by 382.4 kg Single Hole Test Blast Peak Velocity

STAMP Location	Distance (m)	Vertical PPV (μm/s)	Longitudinal PPV (μm/s)	Transverse PPV (μm/s)
4	8,817	20	33	21
7	8,286	30	38	31

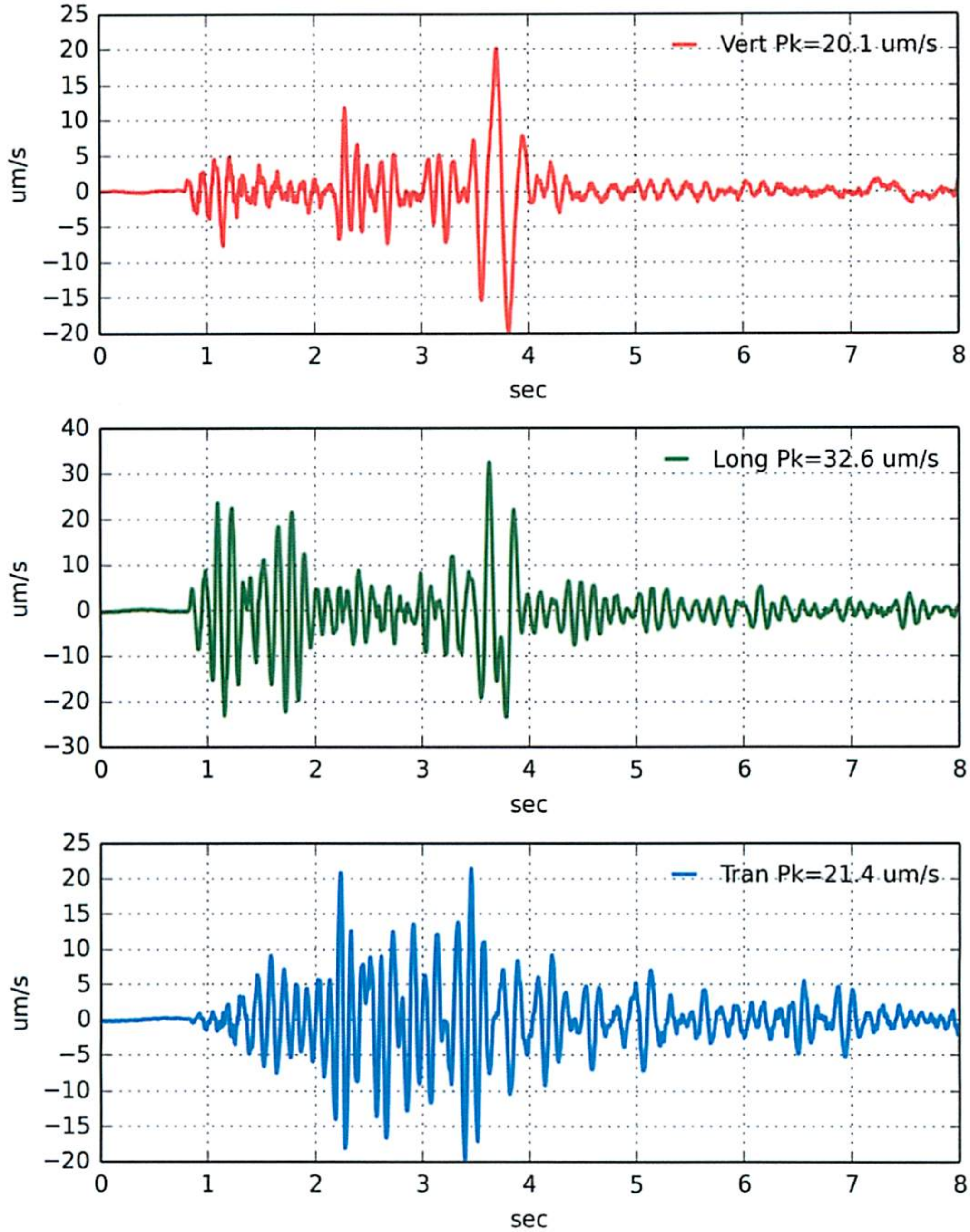
Table 6-4 Ground Vibration Induced by 382.4 kg Single Hole Test Blast Dominant Frequency

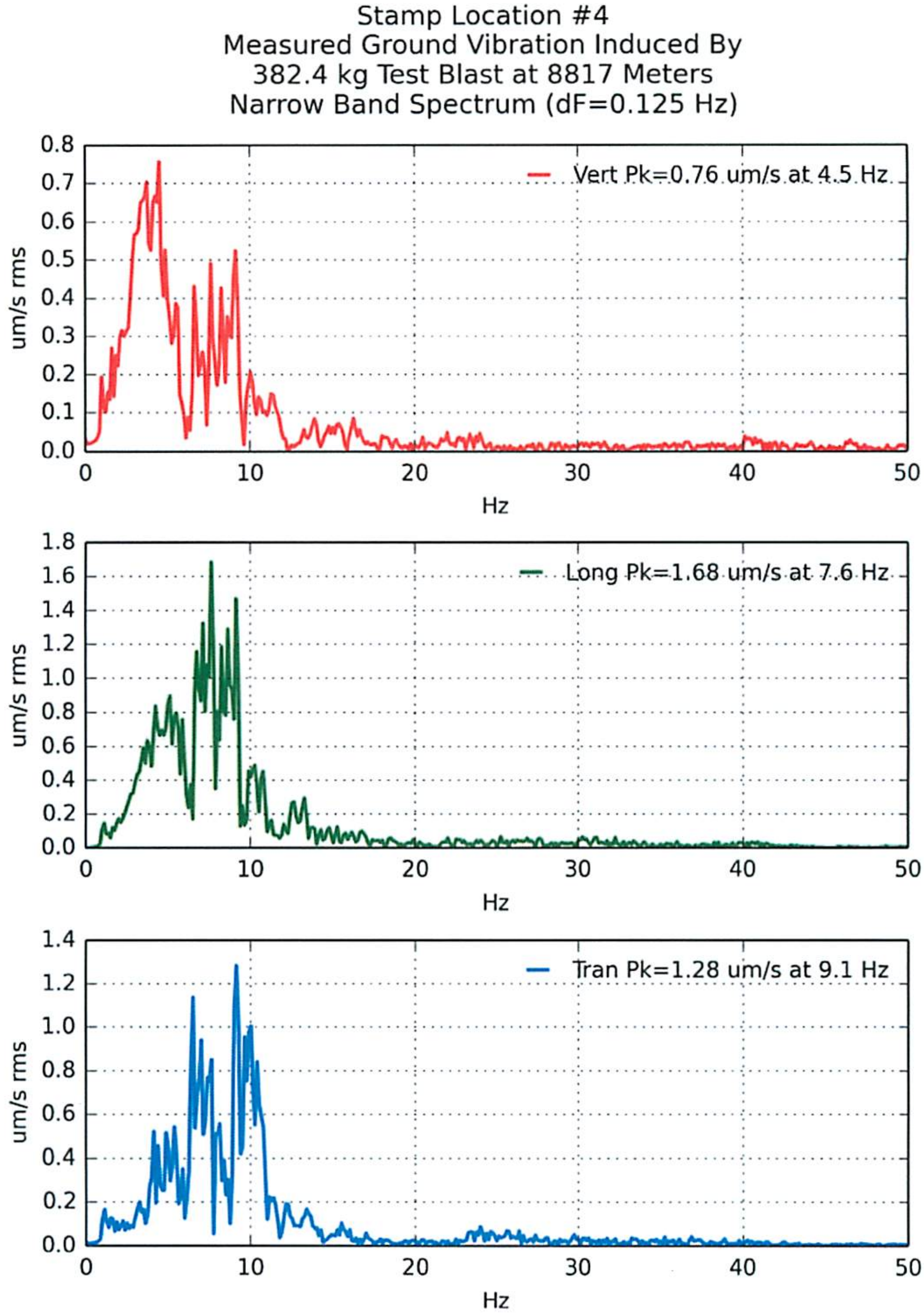
STAMP Location	Distance (m)	Vertical Dominant Frequency (Hz)	Longitudinal Dominant Frequency (Hz)	Transverse Dominant Frequency (Hz)
4	8,817	4.5	7.6	9.1
7	8,286	4.6	7.6	7.1

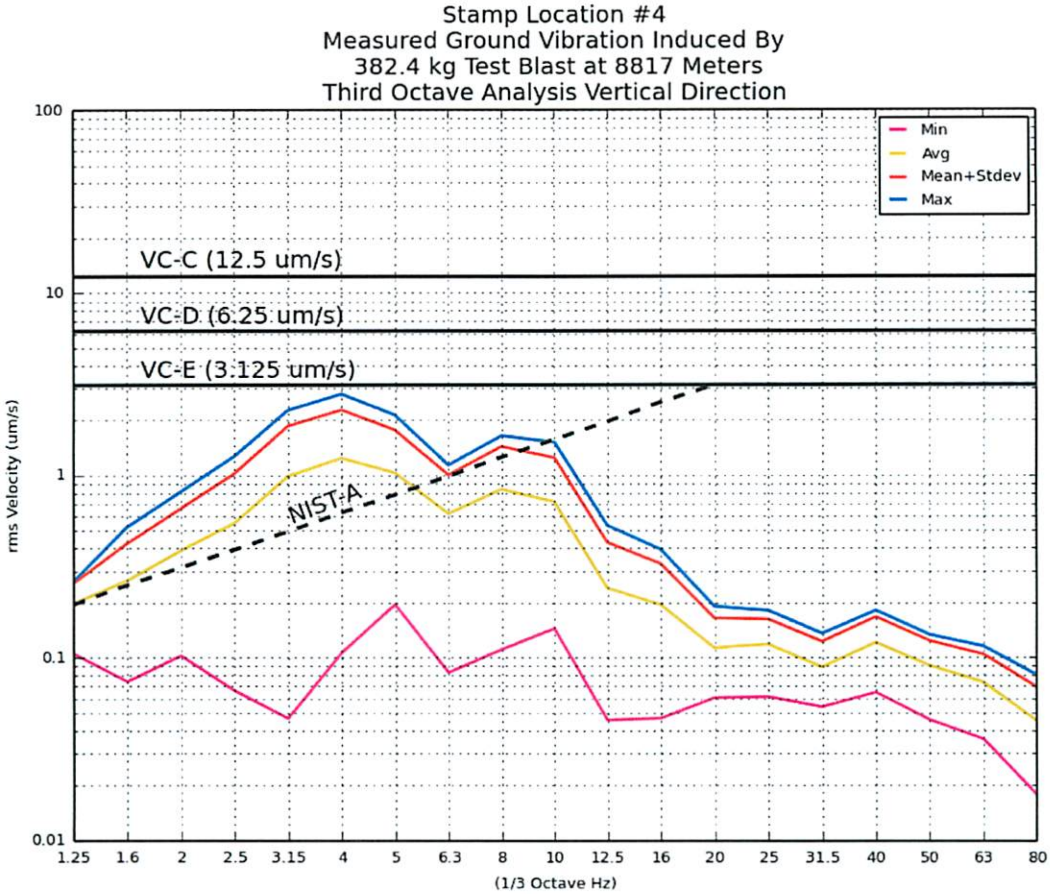
Table 6-5 Ground Vibration Induced by 382.4 kg Single Hole Test Blast 1/3 Octave Max Velocity

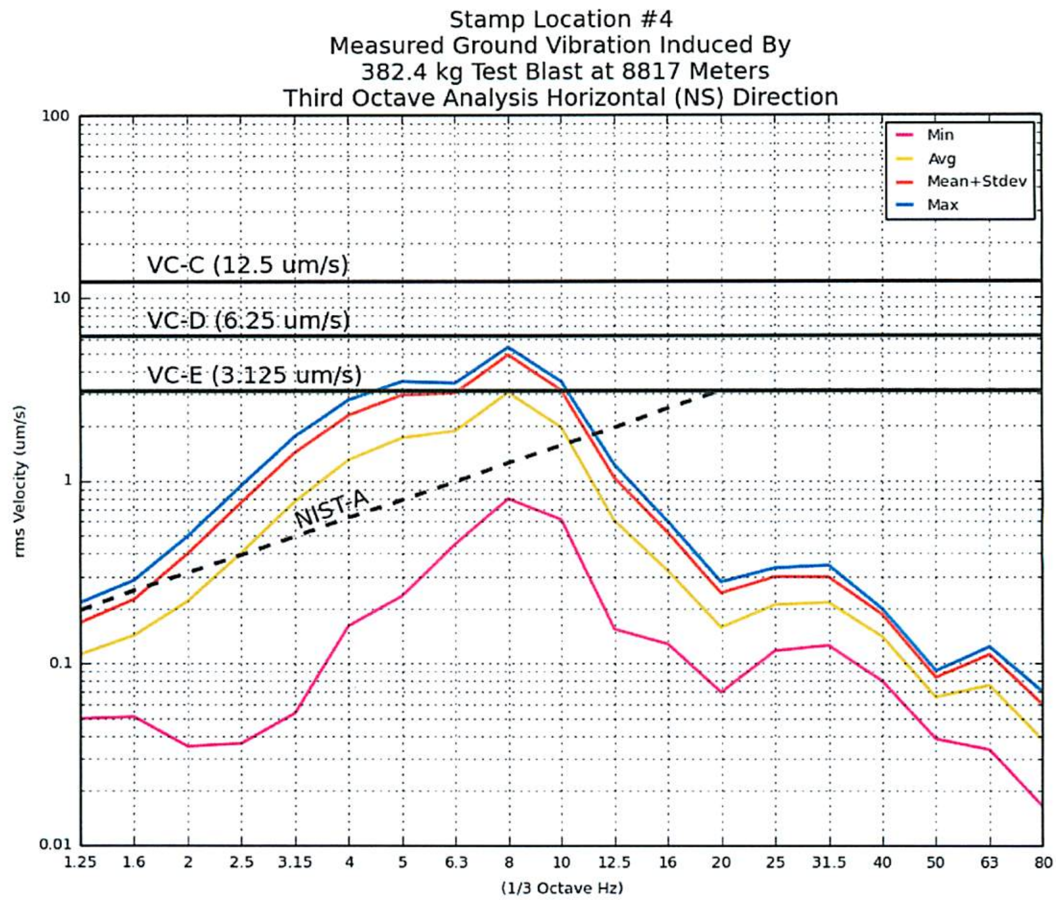
STAMP Location	Distance (m)	Vertical (μm/s rms)	Longitudinal (μm/s rms)	Transverse (μm/s rms)
4	8,817	2.78 VC-E	5.39 VC-D	4.97 VC-D
7	8,286	VC-E 3.49	VC-C 9.57	VC-C 7.44

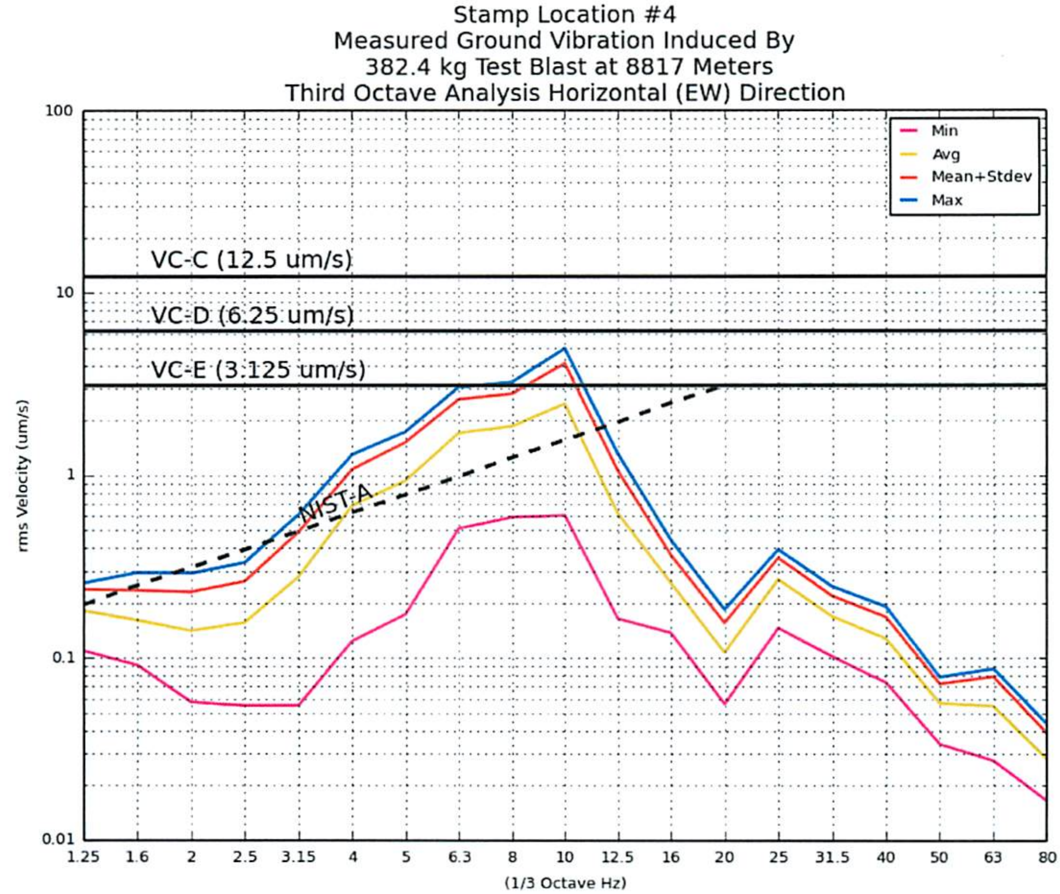
Stamp Location #4
Measured Ground Vibration Induced By
382.4 kg Test Blast at 8817 Meters
Time History

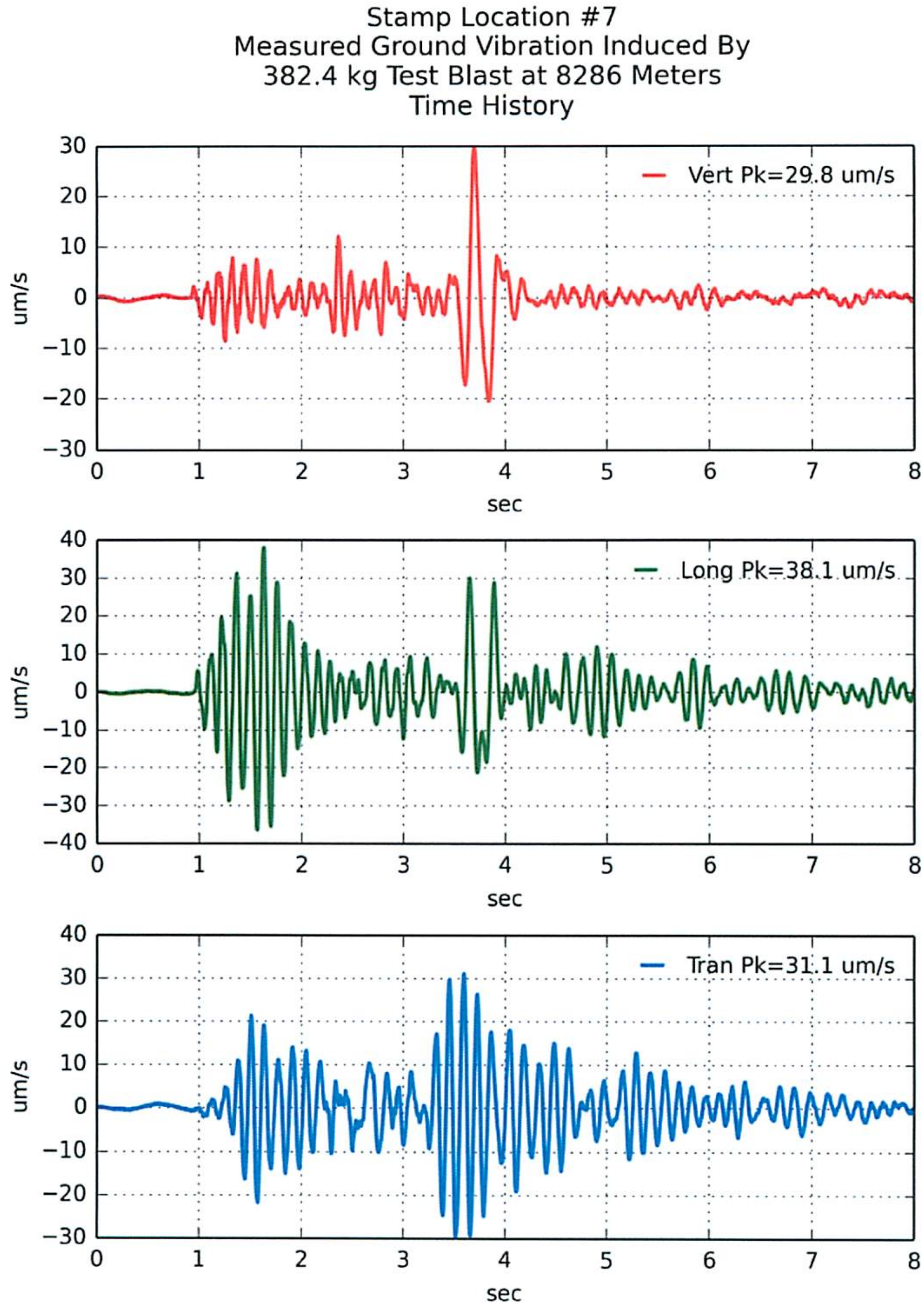


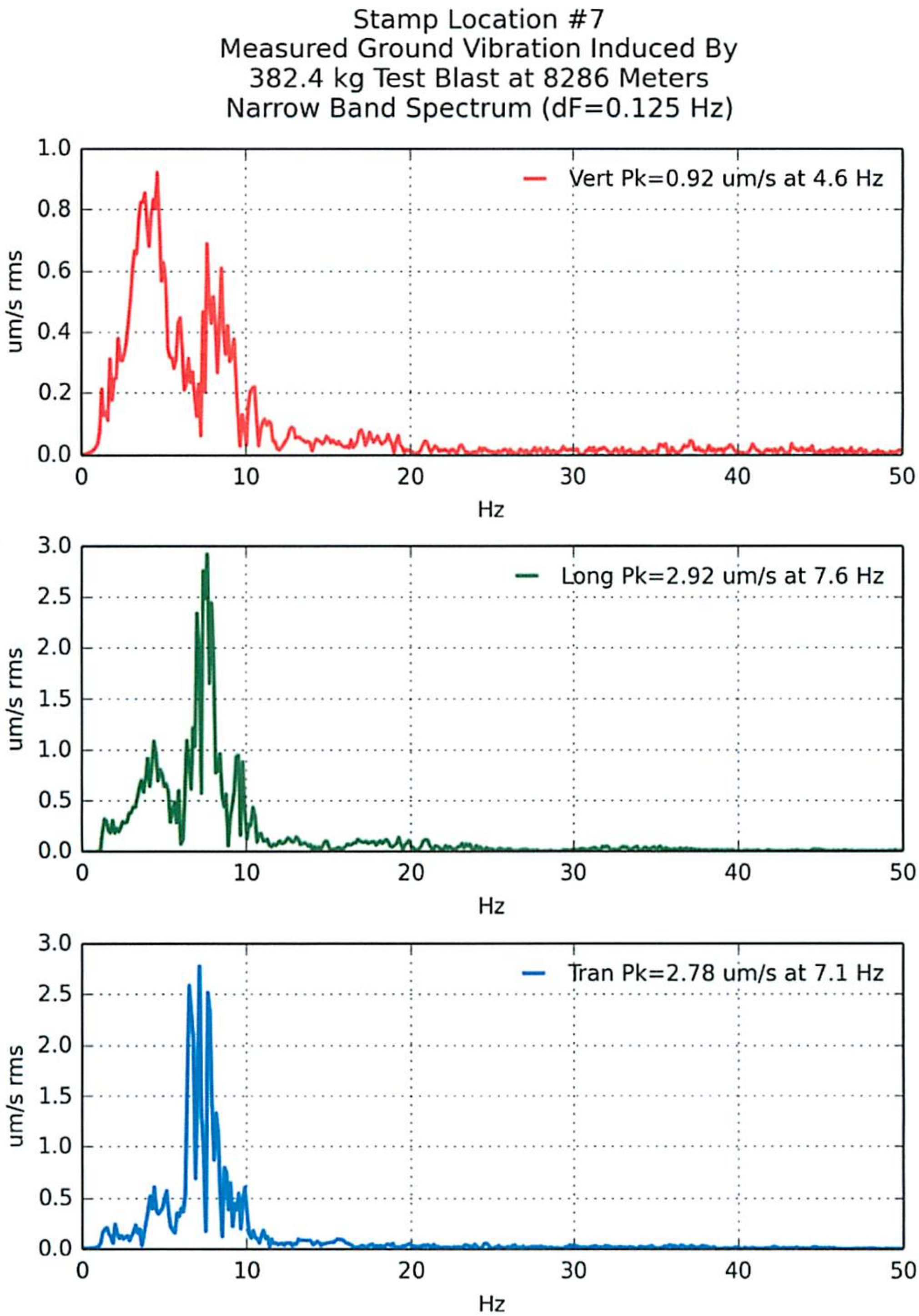

Stamp Location #4
Measured Ground Vibration Induced By
382.4 kg Test Blast at 8817 Meters
Narrow Band Spectrum (dF=0.125 Hz)
Vert Pk=0.76 um/s at 4.5 Hz
Long Pk=1.68 um/s at 7.6 Hz
Tran Pk=1.28 um/s at 9.1 Hz
um/s rms
Hz

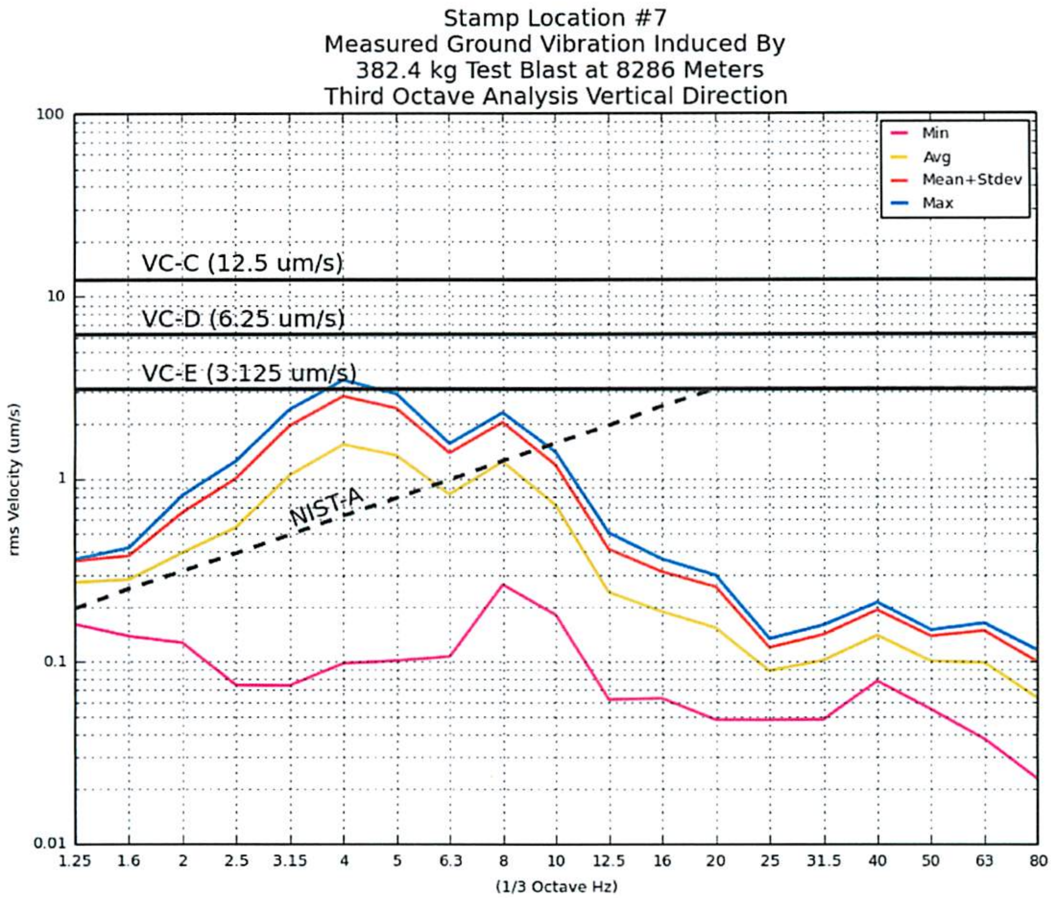

Stamp Location #4
Measured Ground Vibration Induced By
382.4 kg Test Blast at 8817 Meters
Third Octave Analysis Vertical Direction
Min
Avg
Mean+Stdev
Max
VC-C (12.5 um/s)
VC-D (6.25 um/s)
VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
100
10
1
0.1
0.01
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
(1/3 Octave Hz)

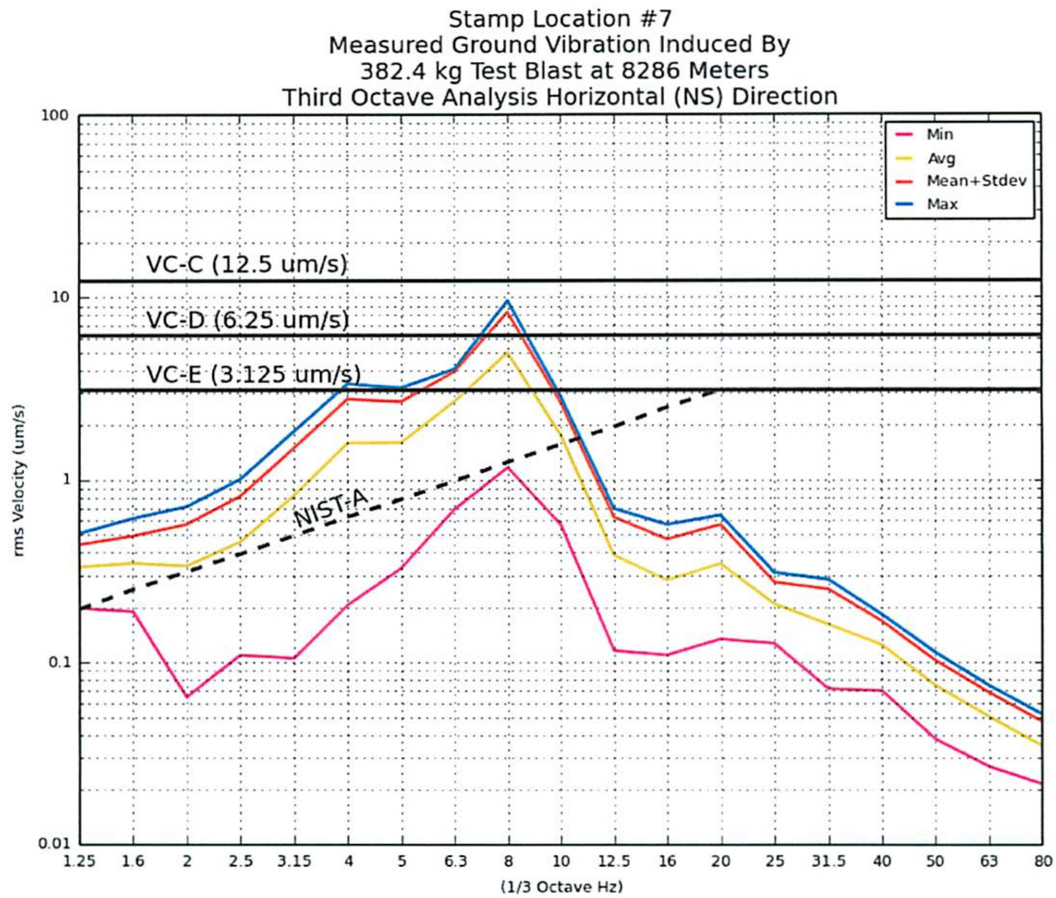

Stamp Location #4
Measured Ground Vibration Induced By
382.4 kg Test Blast at 8817 Meters
Third Octave Analysis Horizontal (NS) Direction
Min
Avg
Mean+Stdev
Max
VC-C (12.5 um/s)
VC-D (6.25 um/s)
VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
100
10
1
0.1
0.01
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
(1/3 Octave Hz)


Stamp Location #4
Measured Ground Vibration Induced By
382.4 kg Test Blast at 8817 Meters
Third Octave Analysis Horizontal (EW) Direction
Min
Avg
Mean+Stdev
Max
VC-C (12.5 um/s)
VC-D (6.25 um/s)
VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
100
10
1
0.1
0.01
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
(1/3 Octave Hz)


Stamp Location #7
Measured Ground Vibration Induced By
382.4 kg Test Blast at 8286 Meters
Time History
Vert Pk=29.8 um/s
Long Pk=38.1 um/s
Tran Pk=31.1 um/s
um/s
sec


Stamp Location #7
Measured Ground Vibration Induced By
382.4 kg Test Blast at 8286 Meters
Narrow Band Spectrum (dF=0.125 Hz)
Vert Pk=0.92 um/s at 4.6 Hz
Long Pk=2.92 um/s at 7.6 Hz
Tran Pk=2.78 um/s at 7.1 Hz
um/s rms
Hz
0
10
20
30
40
50
0.0
0.2
0.4
0.6
0.8
1.0
0.5
1.5
2.0
2.5
3.0


Stamp Location #7
Measured Ground Vibration Induced By
382.4 kg Test Blast at 8286 Meters
Third Octave Analysis Vertical Direction
Min
Avg
Mean+Stdev
Max
VC-C (12.5 um/s)
VC-D (6.25 um/s)
VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
100
10
1
0.1
0.01
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
(1/3 Octave Hz)


Stamp Location #7
Measured Ground Vibration Induced By
382.4 kg Test Blast at 8286 Meters
Third Octave Analysis Horizontal (NS) Direction
Min
Avg
Mean+Stdev
Max
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VC-D (6.25 um/s)
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NIST-A
rms Velocity (um/s)
100
10
1
0.1
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16
20
25
31.5
40
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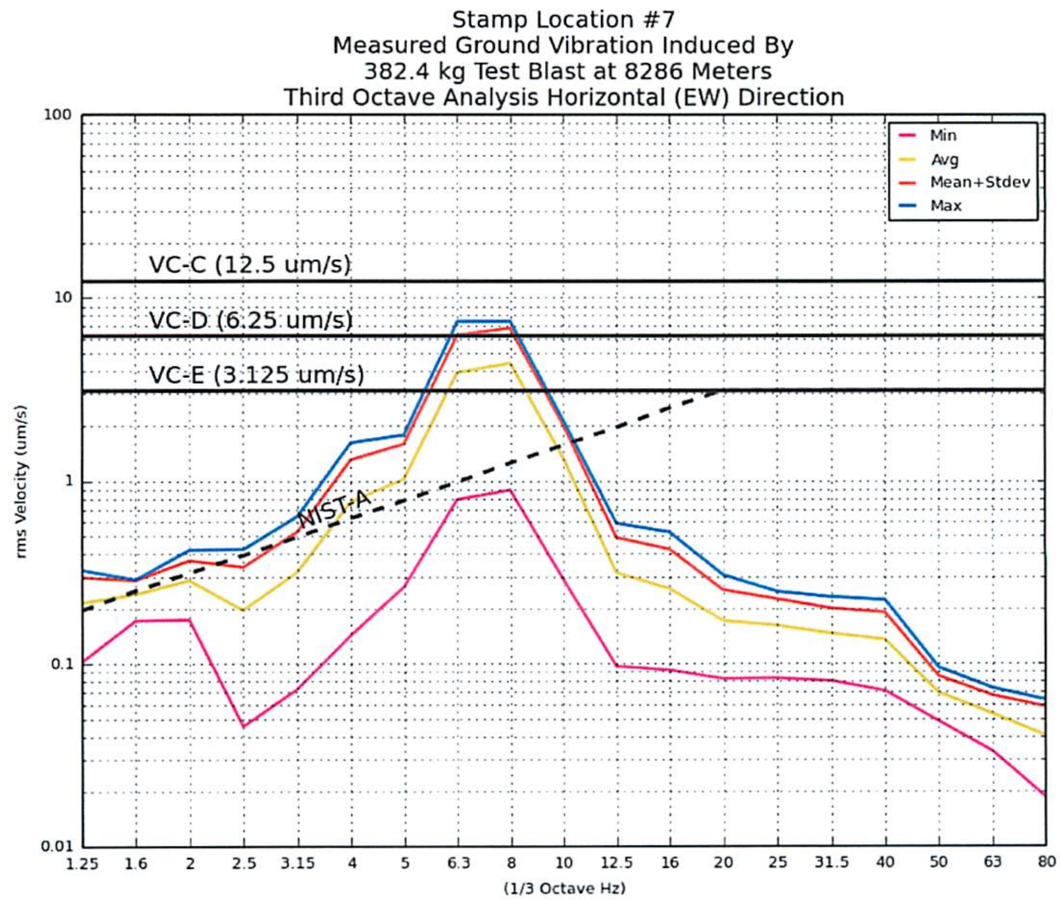
63
80
(1/3 Octave Hz)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Third Octave Analysis Horizontal (EW) Direction
Min
Avg
Mean+Stdev
Max
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VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
100
10
1
0.1
0.01
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
(1/3 Octave Hz)

7 Regression Analysis

In this investigation of ground vibration, it is necessary to determine the equation that describes the rate of attenuation of ground vibration from the proposed quarry to the STAMP area. The dissipation of energy with distance varies from site to site and can only be determined by recording vibration at several distances from the source at the site. This study consisted of using a linear array of seismographs to measure ground vibration between the proposed quarry and the STAMP area resulting from the detonation of a 382 kg. (843 lbs.) confined single hole blast on September 17, 2014. A statistical technique known as Regression Analysis was then performed on the measured data to develop an equation to predict the ground vibration at the STAMP area induced by future blasting at the proposed quarry.

7.1 Discussion of Regression analysis

When a blast is monitored in a method that collects vibration data versus distance and charge weight, it is possible to analyze the data in such a way that it becomes an indicator of the vibration effects for future blasts and not merely a record of past events. This technique may be used to predict future vibrations from production blasting quite confidently, the Office of Surface Mining Reclamation and Enforcement (OSMRE) recognizes this analysis tool as an acceptable method of demonstrating blast vibration regulatory compliance.

In order to determine a site-specific vibration attenuation relationship, a total of forty-three (43) seismic data points were collected from the detonation of the signature blast. A minimum of thirty (30) data pairs is recommended by the OSMRE to complete a confident regression analysis. The collected peak particle velocities are plotted with their corresponding distance on a log-log plot. Figure 7-1 contains a graphical depiction of the predicted ground surface particle motion for all of the data combined. Seismic data points included measurements at the nearest and farthest STAMP property locations relative to the single-hole blast.

The method of least squares was then used to regress the collected data with the modified Bornitz equation to include charge weight. The Bornitz equation takes into account both geometric and material damping.

$$v_2 = v_1 \left(\frac{r_2}{r_1} \right)^n e^{-\alpha (r_2 - r_1)}$$

Equation 7-1
Bornitz Equation

Where:

- V_1, V_2 = PPV at location #1 and #2
- R_1, R_2 = Distance to Location #1 and #2
- N = Wave Spreading Factor
- α = Material Attenuation Factor

7.2 Results of Regression analysis

The relationship between peak particle velocity, charge weight and distance can be obtained by determining the "best fitting" line to the plotted data. The mean (best fit) curve of the plotted data represents the best approximation of the amplitude of the vibrations from a blast at a given distance and charge weight. Statistically, one half of all vibrations recorded at a given distance should exceed the mean amplitude, the other half should be less than the mean. The regression analysis of the peak particle velocity vs. distance data for plotted in Figure 7-1. The calculated best-fit equation is:

$$PPV = 0.0017\sqrt{w}\left(\frac{91.7}{d}\right)^{0.938} e^{-0.000293(d-91.7)}$$

Equation 7-2
Longitudinal
Confined
(50% Prediction)

Where:

PPV = Ground Surface Peak Particle Velocity (m/s)

w = Explosive Charge Weight (kg)

d = Distance from Charge (meters)

The coefficient of determination (goodness of fit) for the array was 0.95. OSMRE defines a minimum acceptable value of 0.70. The standard deviation for the array was 0.368. The standard deviation should be less than 0.50 according to OSMRE.

The collection of scaled distance vs. particle velocity data for the determination of attenuation relationships will result in a good deal of scatter about the mean line. This scatter can result because of changes in geologic conditions, geophone coupling, or different wave types at the peak. Because of this scatter it is often prudent to determine the prediction interval as an estimate on the probability where future observations will fall. The 95% prediction intervals Lines are computed by adding multiples of the standard error of the estimate adjusted for the number of data pairs. The confidence lines for 95 percent shown on Figure 7-1.

Statistically, there exists a 95 percent probability that the peak particle velocity generated from a blast at a given scaled distance will not exceed the 95 percent confidence line intercept at that scaled distance. In other words, the 95 percent confidence value is the particle velocity that will not be exceeded 95 out of 100 blasts at that scaled distance.

The equation of the 95 percent confidence line calculated for the peak particle velocity vs. charge weight is shown in Equation 7-3:

$$PPV = 0.0037\sqrt{w}\left(\frac{91.7}{d}\right)^{0.938} e^{-0.000293(d-91.7)}$$

Equation 7-3
Longitudinal
Confined
(95% Upper Prediction)

PPV = Ground Surface Peak Particle Velocity (m/s)

w = Explosive Charge Weight (kg)

d = Distance from Charge (meters)

7.3 Peak vibration level vs Sensor Direction

Analysis of the measured data shows that the blast induced surface ground vibrations at the STAMP is significantly greater in the longitudinal direction. Transverse and vertical vibrations were measured to be 30% less than the longitudinal direction. The developed regression equations should be reduced by 30% for transverse and vertical ground waves.

Table 7-1 Ground Vibration Induced by 382.4 kg Single Hole Test Blast Peak Velocity

STAMP Location	Distance (m)	Vertical PPV (µm/s)	Longitudinal PPV (µm/s)	Transverse PPV (µm/s)
4	8,817	20	33	21
7	8,286	30	38	31

Table 7-2 Ground Vibration Reduction Factor Vertical and Transverse Directions

Location Description	PPV (µm/s)	Ratio to Longitudinal
Location 4 Vert	20	20 / 33 = 0.61
Location 4 Tran	21	21 / 33 = 0.64
Location 7 Vert	30	30 / 38 = 0.79
Location 7 Tran	31	31 / 38 = 0.82

7.4 Reduction in Prediction Equations Due to Confinement

The measured ground peak particle velocity levels used in the development of the 95% and mean prediction equations are biased due to the high confinement of the single-hole test blast. The test blast consisted of a single borehole loaded with explosives. There was no free face for this test hole and the amount of stemming utilized was 14.8 meters (48.5 ft). Confined explosives do not leave adequate space for broken rock to expand resulting in larger than normal ground vibrations. Explosives are most effective when there is a free face parallel to the explosive column. Future quarry blasting will have a free face and appropriate stemming heights of 3.7 meter (12 ft) to 4.6 meter (15 ft) will be utilized. In this scenario, the majority of the explosive energy is consumed by fracturing and moving the rock with less energy directed to ground vibration.

The International Society of Explosive Engineers Handbook 18th edition page 567 and 568 lists the ground response factor used in predicting the vibration intensity vs. scaled distance. For a blast with average confinement a ground response factor of 160 may be selected, and for a blast with that is very heavily confined a factor of 605 may be used. Thus, highly confined buried explosive are expected to generate ground vibration PPV levels 3.78 times greater than unconfined explosives of the same weight.

It is then justified that the upper 95% prediction equations determined in the regression analysis be reduced to account for normally confined explosives by a factor if 3.78. The following equations show the in the adjusted 95% upper bound prediction equations for unconfined explosives:

$$PPV = \left(\frac{0.0037}{3.78}\right)\sqrt{w}\left(\frac{91.7}{d}\right)^{0.938} e^{-0.000293(d-91.7)}$$

Equation 7-4
Longitudinal
Unconfined
(95% Prediction)

$$PPV = \left(\frac{0.0037 \cdot 0.7}{3.78}\right)\sqrt{w}\left(\frac{91.7}{d}\right)^{0.938} e^{-0.000293(d-91.7)}$$

Equation 7-5
Vertical and
Transverse Unconfined
(95% Prediction)

Where:

PPV = Ground Surface Peak Particle Velocity (m/s)

W = Explosive Charge Weight (kg)

D = Distance from Charge (meters)

Table 7-3 Ground Vibration Measurements From Linear Array of Seismographs

N	Distance (m)	Peak Particle Velocity (mm/s)
1	91.7	28,826
2	108.4	24,575
3	127.6	24,125
4	145.0	29,007
5	161.9	39,365
6	180.4	25,898
7	198.4	29,266
8	215.9	22,014
9	240.0	15,799
10	268.1	12,949
11	304.1	11,913
12	340.1	8,288
13	384.9	5,179
14	437.9	5,438
15	476.7	7,874
16	481.7	4,661
17	493.5	5,956
18	516.3	4,661
19	517.7	3,934
20	520.0	4,143
21	526.1	3,366
22	548.9	4,661
23	556.2	3,178
24	580.3	2,591
25	631.9	2,850
26	698.7	3,048
27	757.6	2,073
28	827.6	3,239
29	939.8	1,684
30	1,024.9	1,494
31	1,114.8	3,426
32	1,202.5	1,425
33	1,389.9	2,202
34	1,462.6	2,271
35	1,642.9	1,295
36	1,863.8	1,494
37	2,212.5	1,684
38	2,669.6	648
39	3,784.8	318
40	4,452.4	389
41	4,731.3	259
42	8,286.0	38
43	8,817.0	33

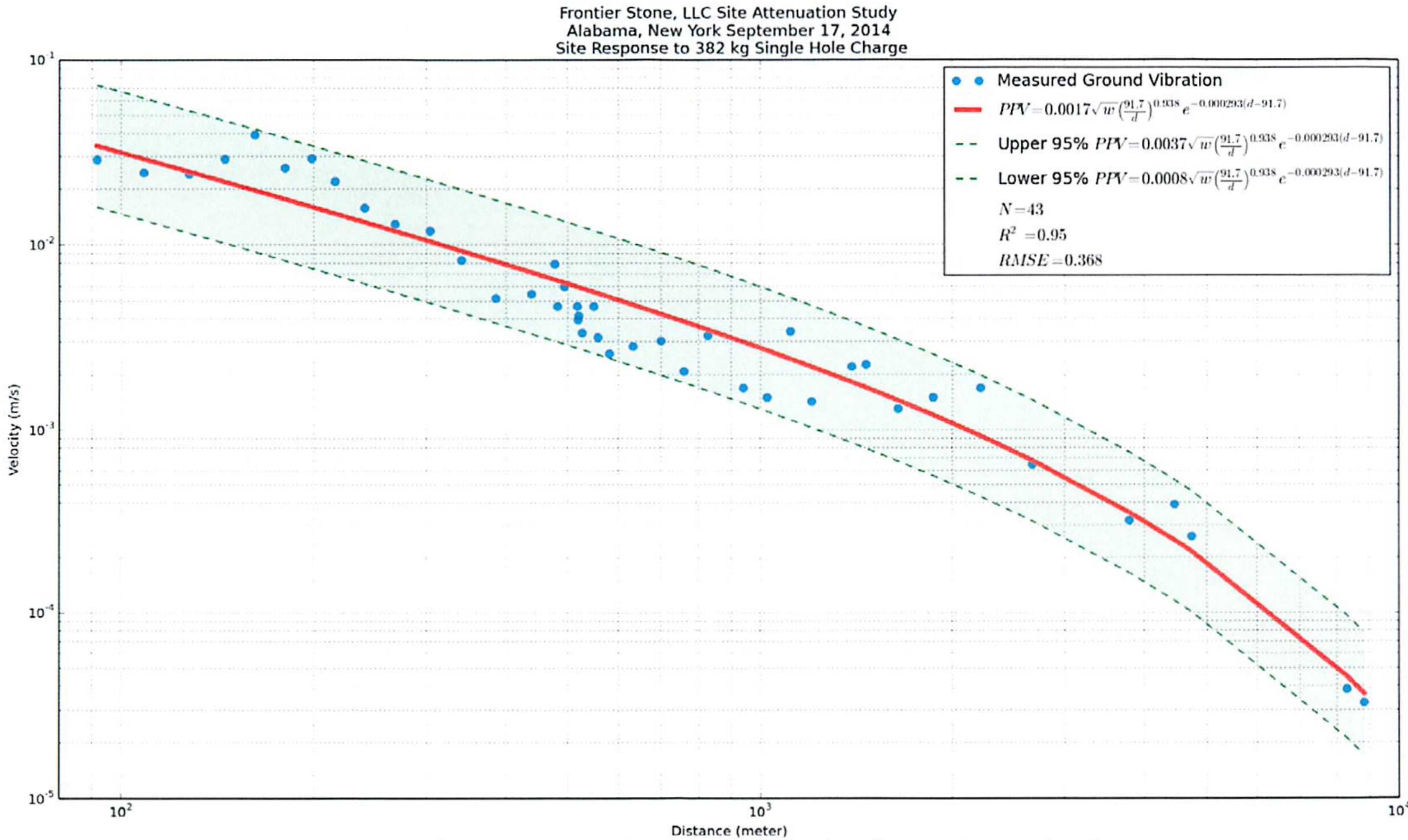


Figure 7-1 Ground Reponse to Confined Single Hole Blast (regression Analysis)

8 Predicted ground vibration levels to production blast

This section predicts ground vibration levels at the STAMP based on the regression analysis and the single-hole seed waveform method to simulate a millisecond delayed multiple hole production blast.

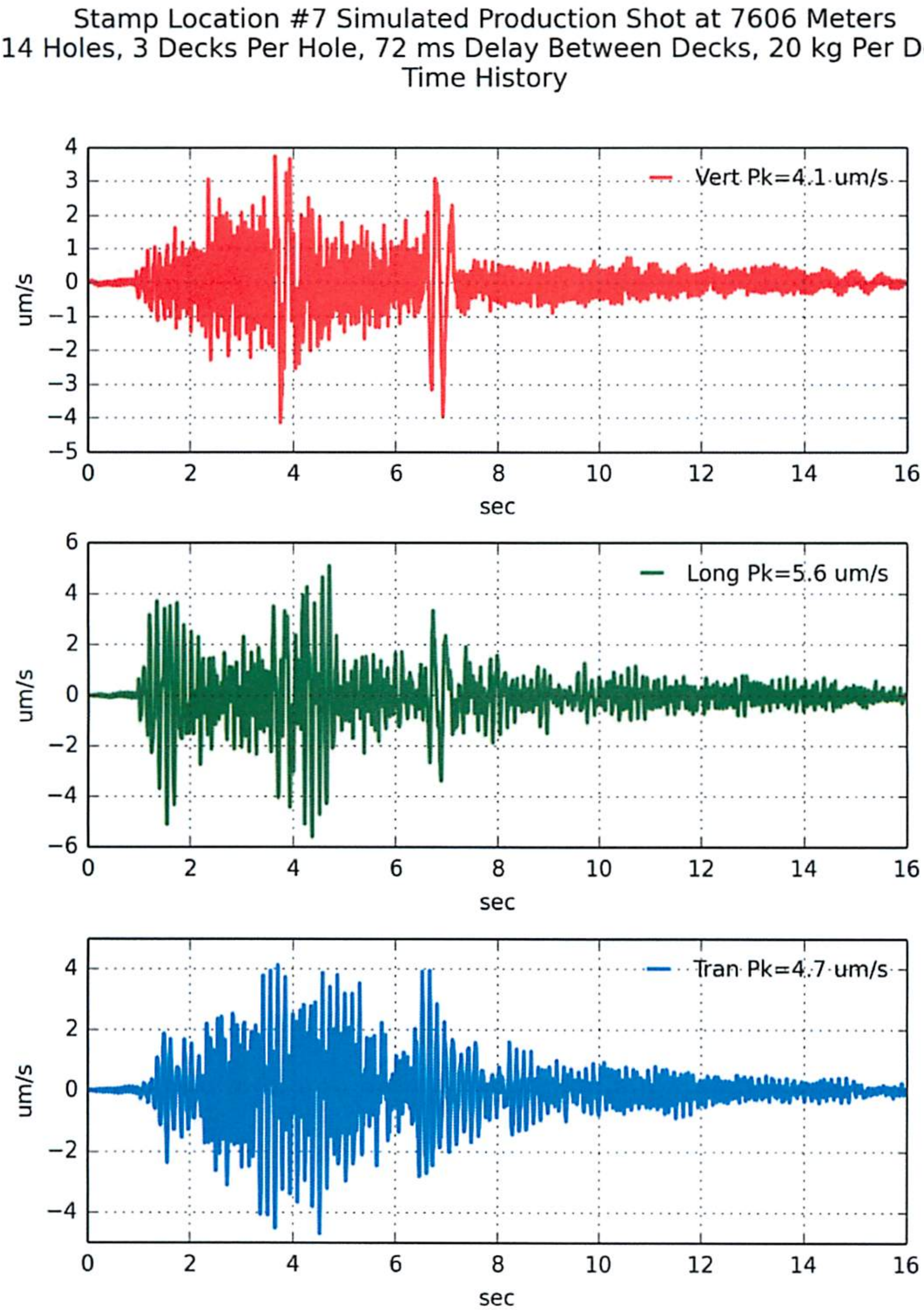
8.1 Predicted Multihole Production Shot Vibration Levels at 7606 meters

The closest blasting will occur at 7,606 meters from Location 7. A fourteen (14) hole production shot was simulated with 101.6 mm (4 inch) diameter holes with 3 explosive decks per hole. Timing analysis identified 72 ms as the optimum delay period between explosive charges for maximum reduction in ground vibration from destructive interference in the seismic waves. Delay periods less than 50 ms between explosive charges are expected to increase ground vibration levels at the STAMP due to constructive reinforcement between the seismic waves.

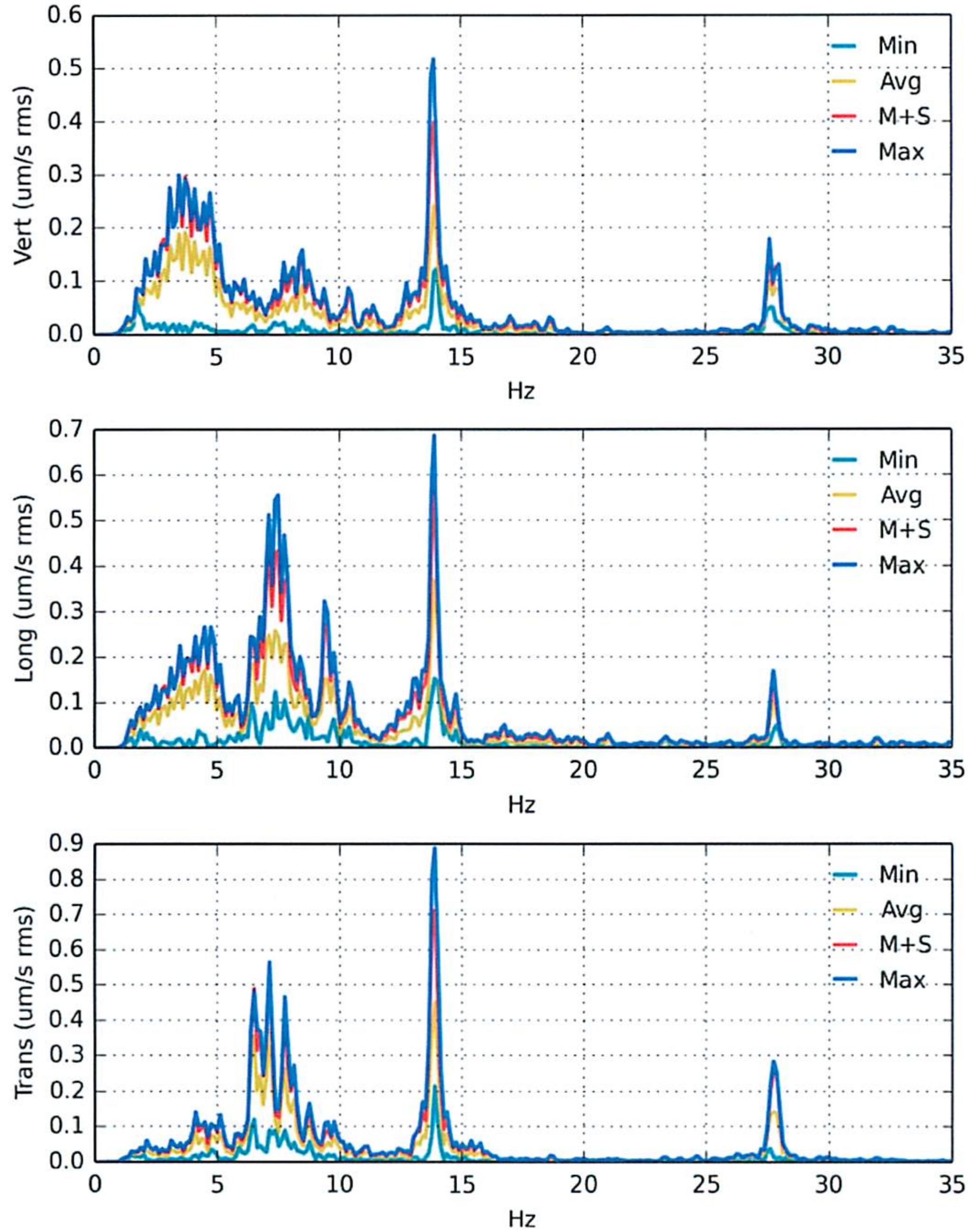
Three production blast simulations are reported using 25 ms, 50 ms, and 72 ms charge delays. The production shot time history was created using convolution of the multi-hole delay timing signal with the recorded single hole blast at Location 7 scaled based on the 95% confidence equation. The resulting waveform was then analyzed and compared with the 1/3 octave vibration criteria. The following graphs show the predicted time history and spectrum, and the comparison with the VC-E and NIST-A vibration criteria.

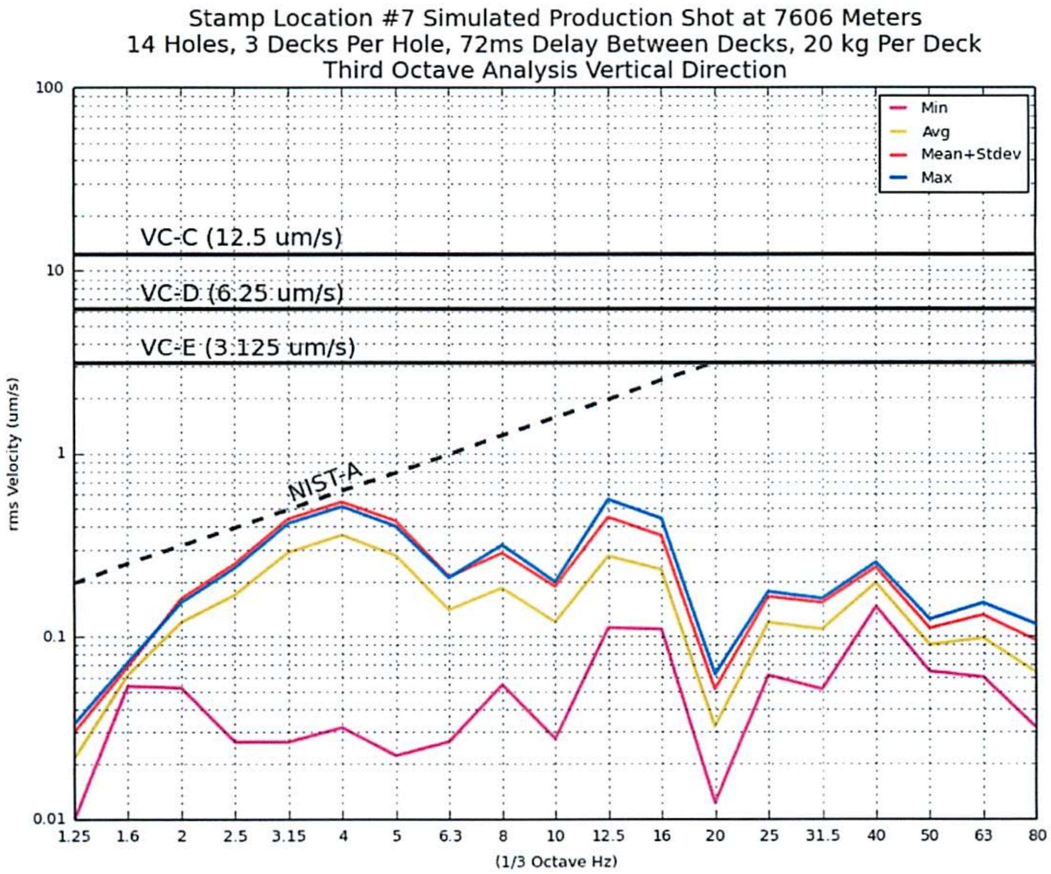
Table 8-1 Summary of Multihole Blasts Simulations

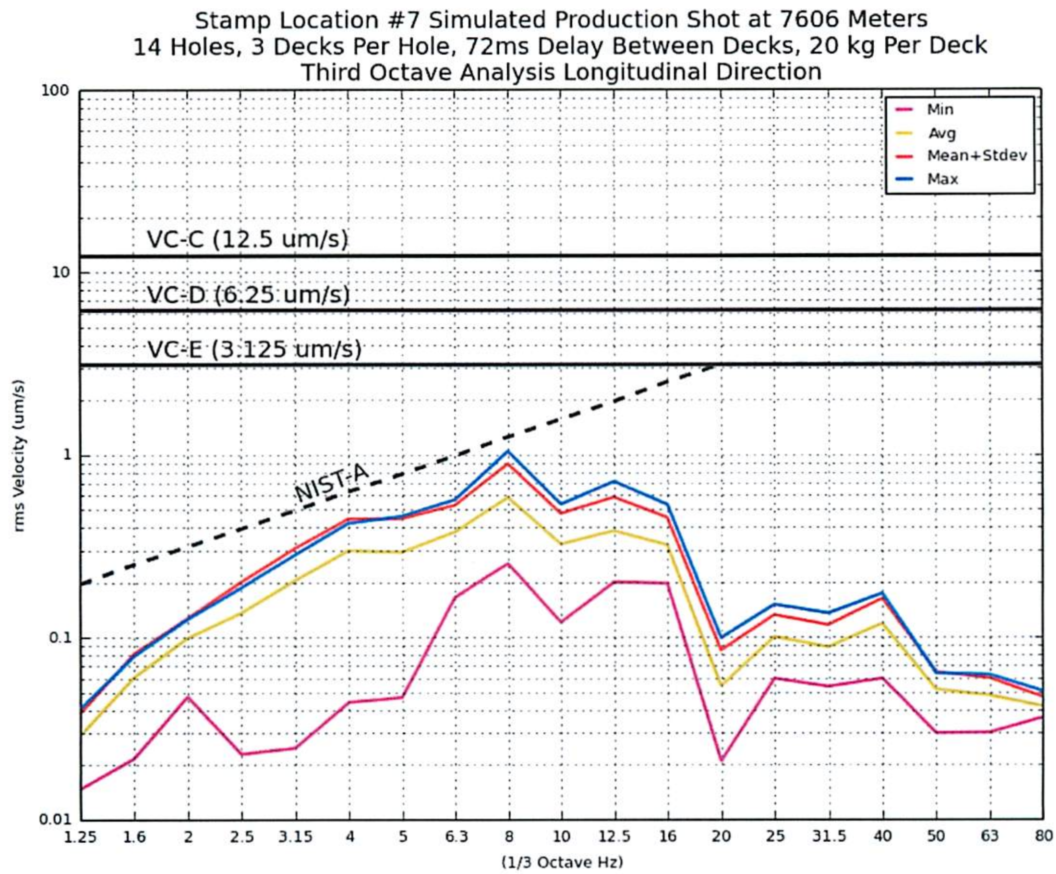
Delay (ms)	Vertical	Longitudinal	Transverse
72	Meets Both NIST-A and VC-E	Meets Both NIST-A and VC-E	Meets Both NIST-A and VC-E
50	Slightly Exceeds NIST-A Meets VC-E	Slightly Exceeds NIST-A Meets VC-E	Meets Both NIST-A and VC-E
25	Exceeds NIST-A Meets VC-E	Exceeds NIST-A Meets VC-E	Exceeds NIST-A Meets VC-E

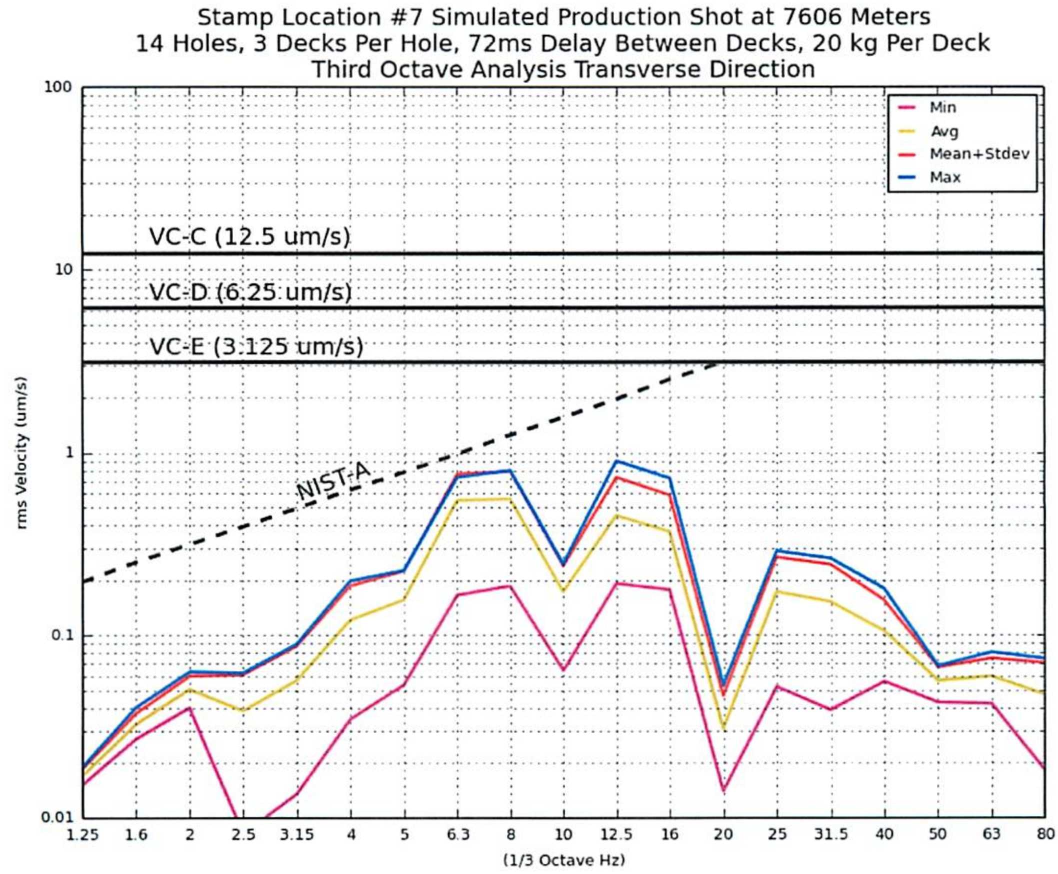

Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 72 ms Delay Between Decks, 20 kg Per Deck
Time History
Vert Pk=4.1 um/s
Long Pk=5.6 um/s
Tran Pk=4.7 um/s
um/s
sec

Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 72 ms Delay Between Decks, 20 kg Per Deck
Narrow Band Spectrum Hann Window 80% Overlap (df=0.125 Hz)

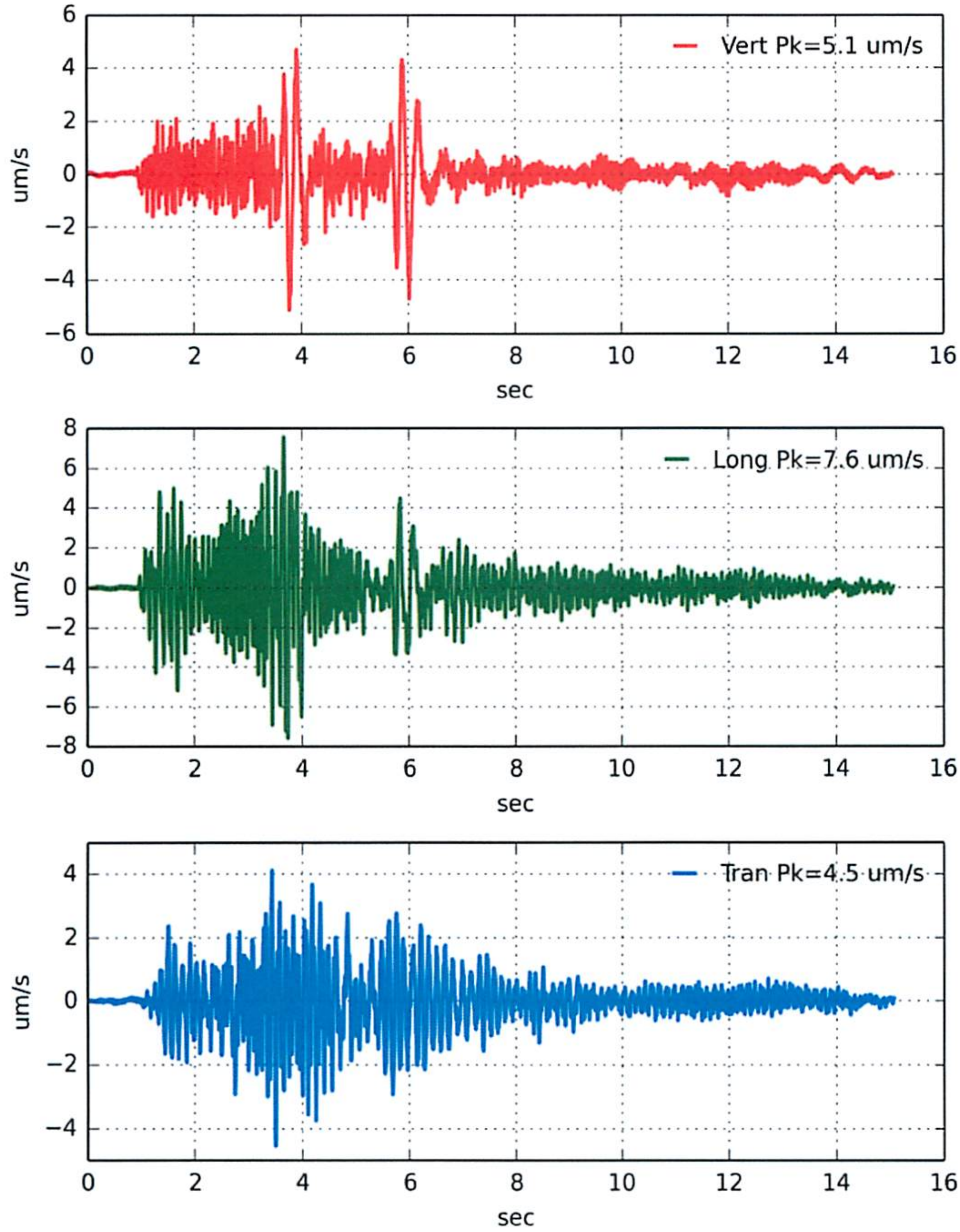



Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 72ms Delay Between Decks, 20 kg Per Deck
Third Octave Analysis Vertical Direction
Min
Avg
Mean+Stdev
Max
VC-C (12.5 um/s)
VC-D (6.25 um/s)
VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
100
10
1
0.1
0.01
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
(1/3 Octave Hz)

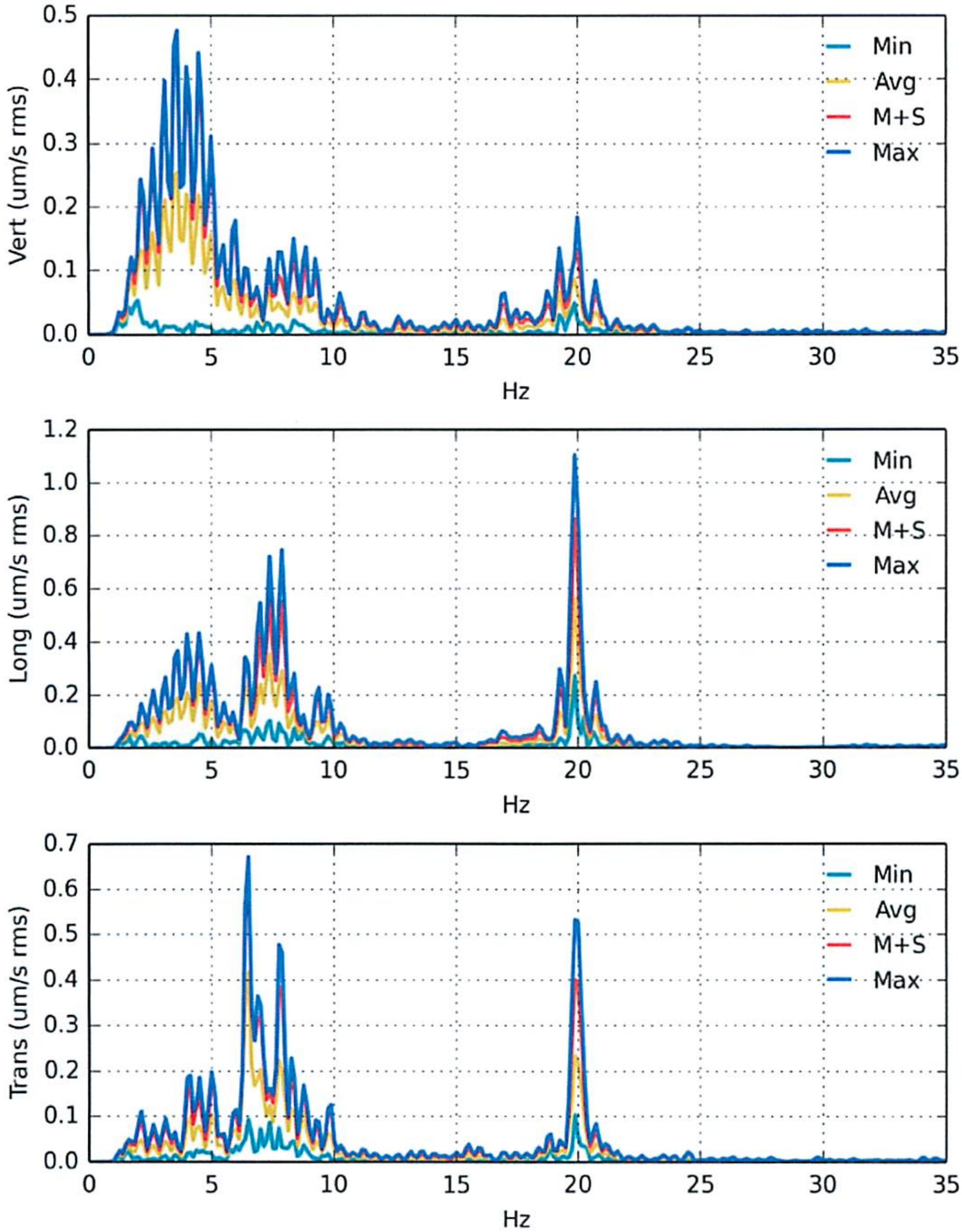

Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 72ms Delay Between Decks, 20 kg Per Deck
Third Octave Analysis Longitudinal Direction
Min
Avg
Mean+Stdev
Max
VC-C (12.5 um/s)
VC-D (6.25 um/s)
VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
100
10
1
0.1
0.01
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
(1/3 Octave Hz)

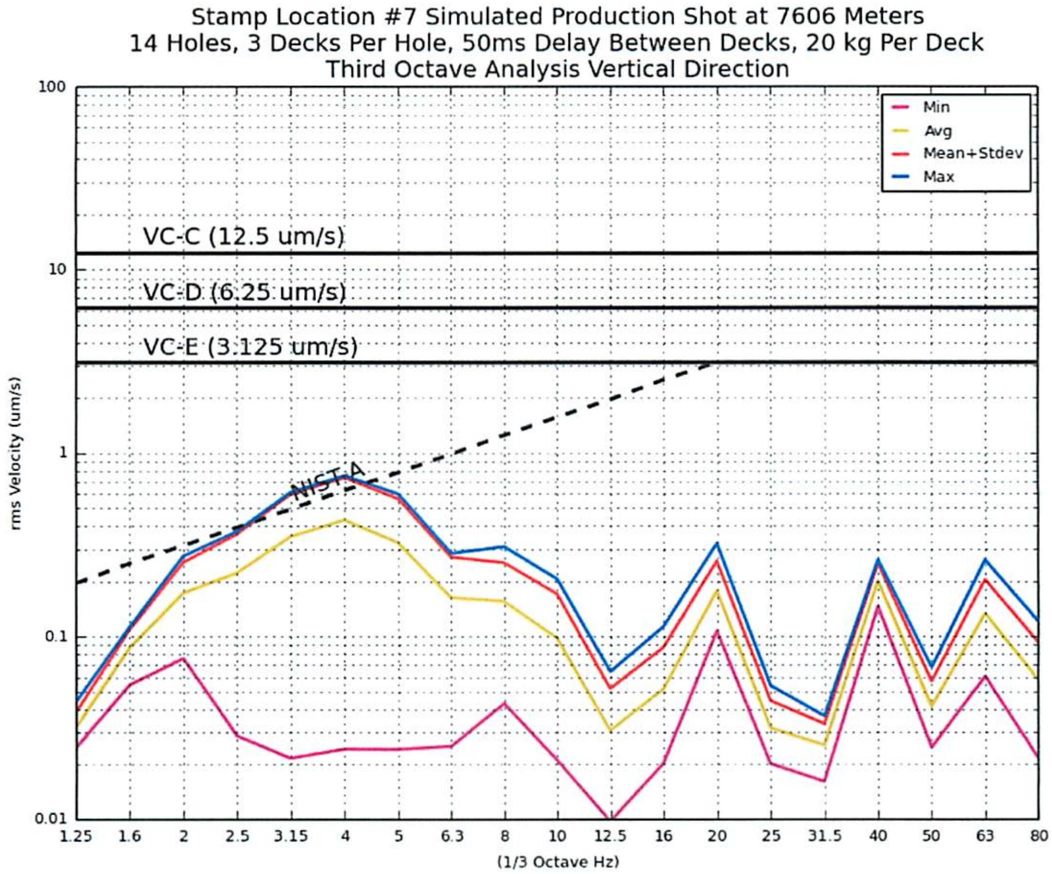

Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 72ms Delay Between Decks, 20 kg Per Deck
Third Octave Analysis Transverse Direction
Min
Avg
Mean+Stdev
Max
VC-C (12.5 um/s)
VC-D (6.25 um/s)
VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
100
10
1
0.1
0.01
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
(1/3 Octave Hz)

Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 50 ms Delay Between Decks, 20 kg Per Deck
Time History



Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 50 ms Delay Between Decks, 20 kg Per Deck
Narrow Band Spectrum Hann Window 80% Overlap (df=0.125 Hz)




Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 50ms Delay Between Decks, 20 kg Per Deck
Third Octave Analysis Vertical Direction
Min
Avg
Mean+Stdev
Max
VC-C (12.5 um/s)
VC-D (6.25 um/s)
VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
100
10
1
0.1
0.01
1.25
1.6
2
2.5
3.15
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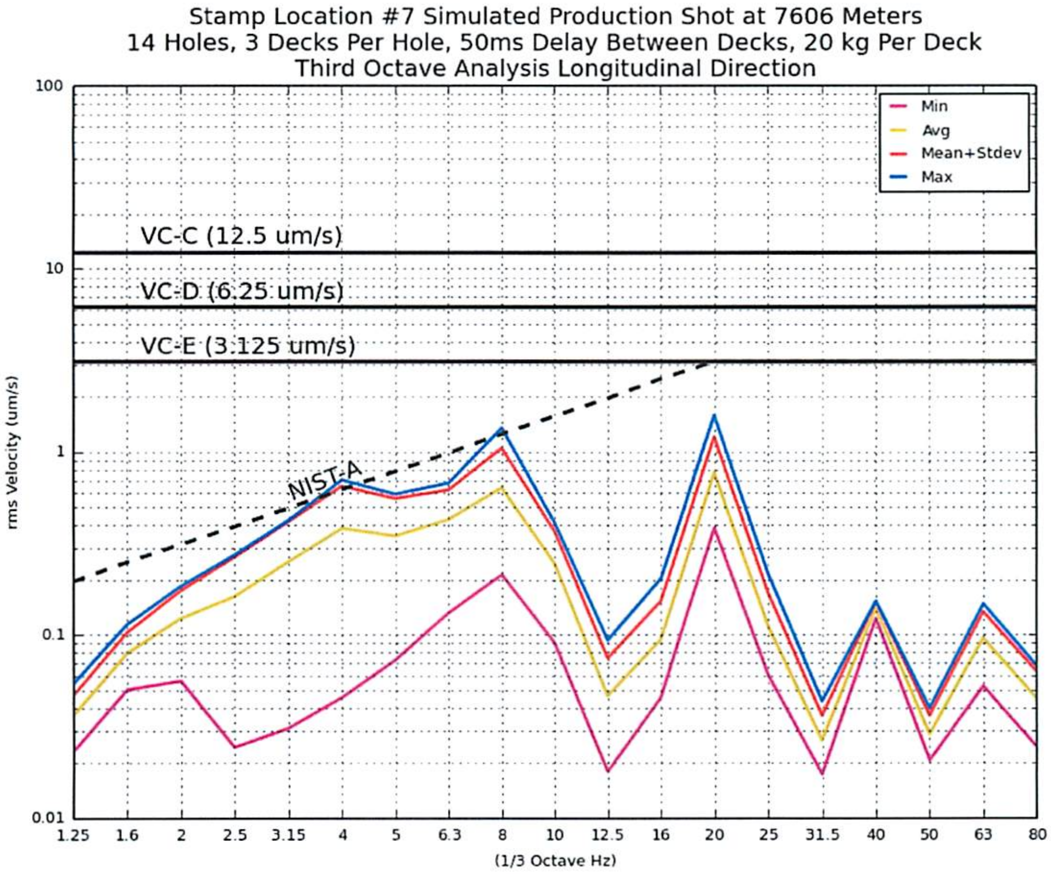
12.5
16
20
25
31.5
40
50
63
80
(1/3 Octave Hz)


Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 50ms Delay Between Decks, 20 kg Per Deck
Third Octave Analysis Longitudinal Direction
Min
Avg
Mean+Stdev
Max
VC-C (12.5 um/s)
VC-D (6.25 um/s)
VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
100
10
1
0.1
0.01
1.25
1.6
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2.5
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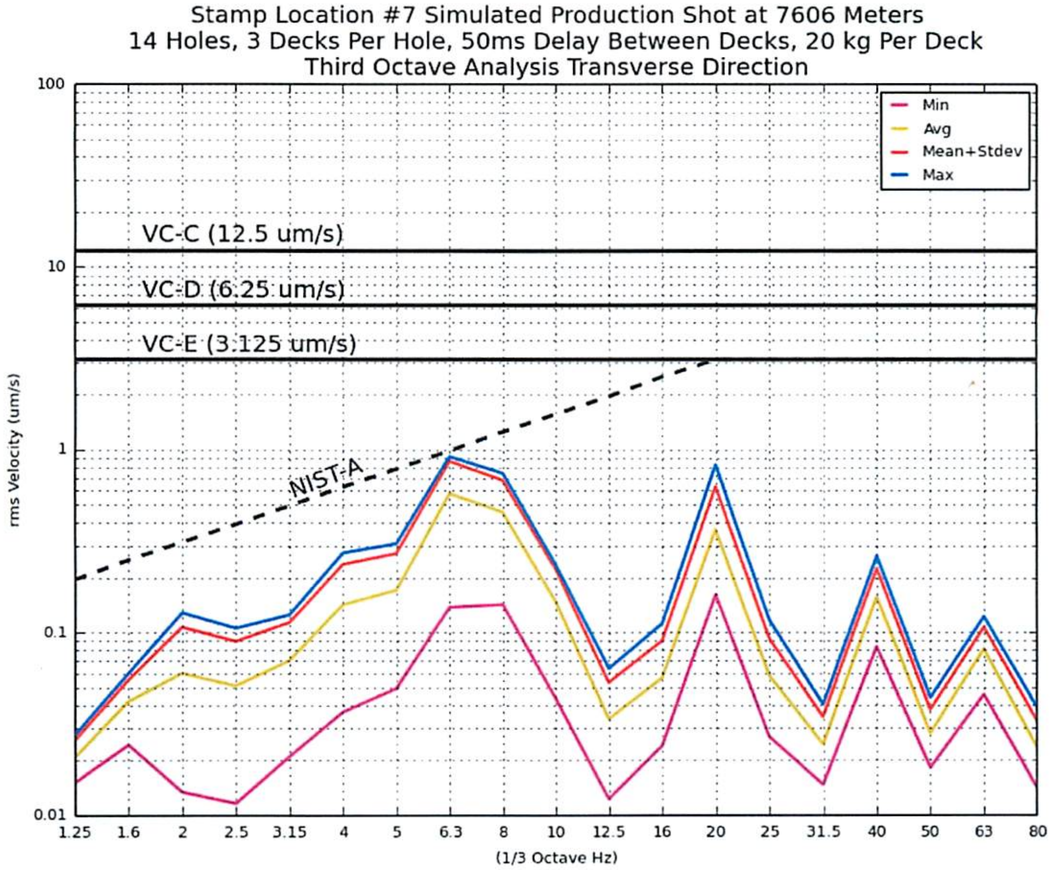
80
(1/3 Octave Hz)


Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 50ms Delay Between Decks, 20 kg Per Deck
Third Octave Analysis Transverse Direction
Min
Avg
Mean+Stdev
Max
VC-C (12.5 um/s)
VC-D (6.25 um/s)
VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
100
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1
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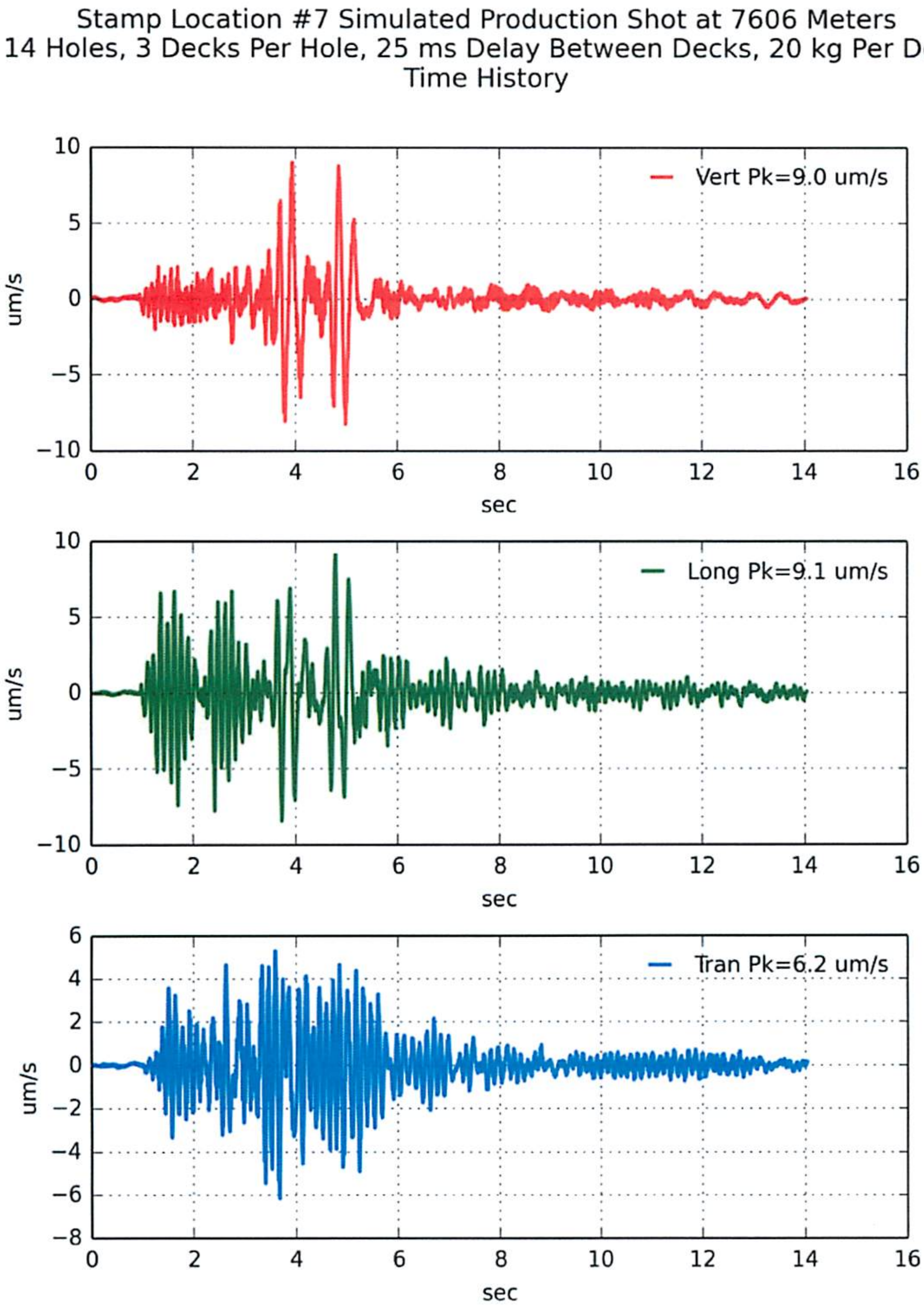
(1/3 Octave Hz)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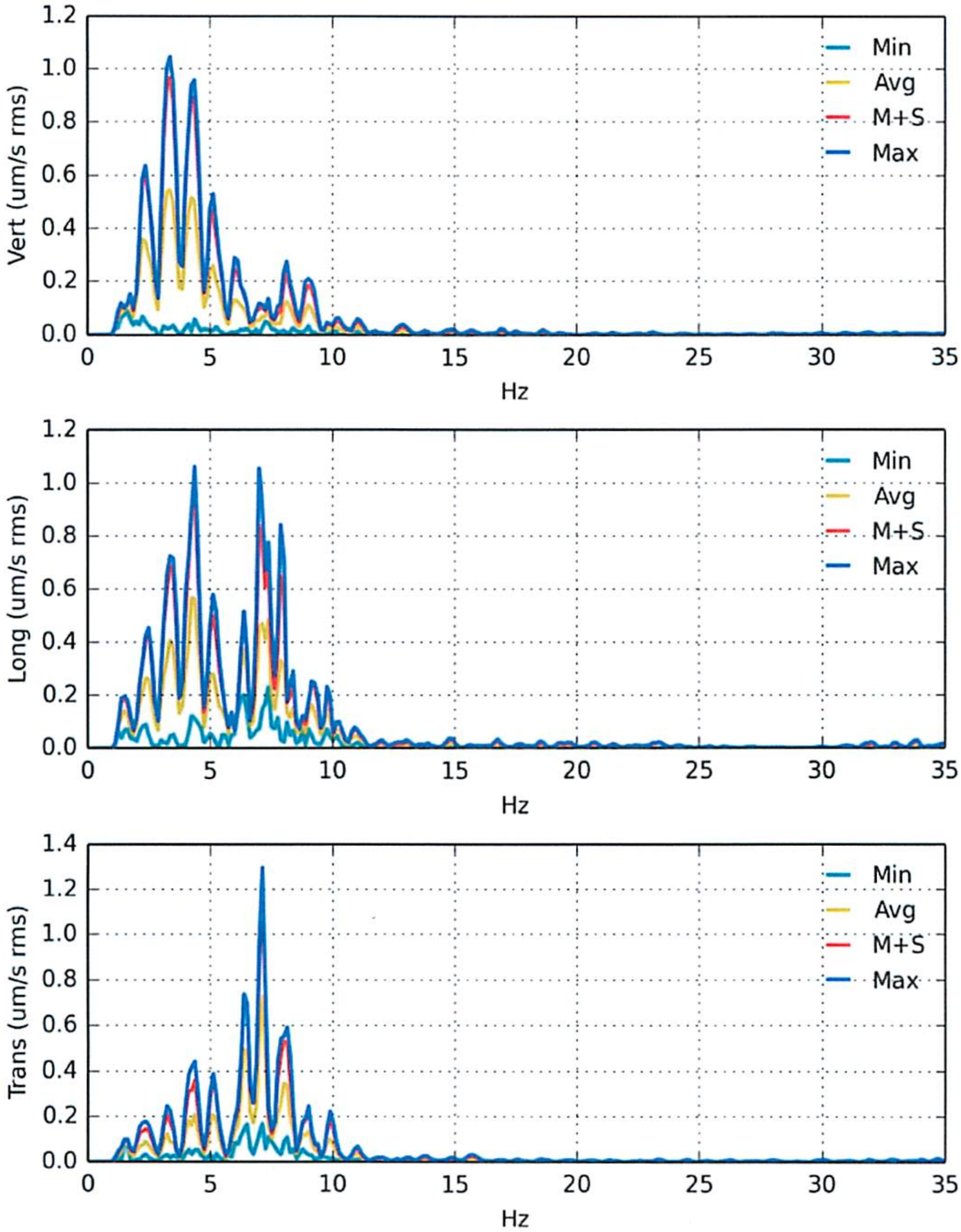
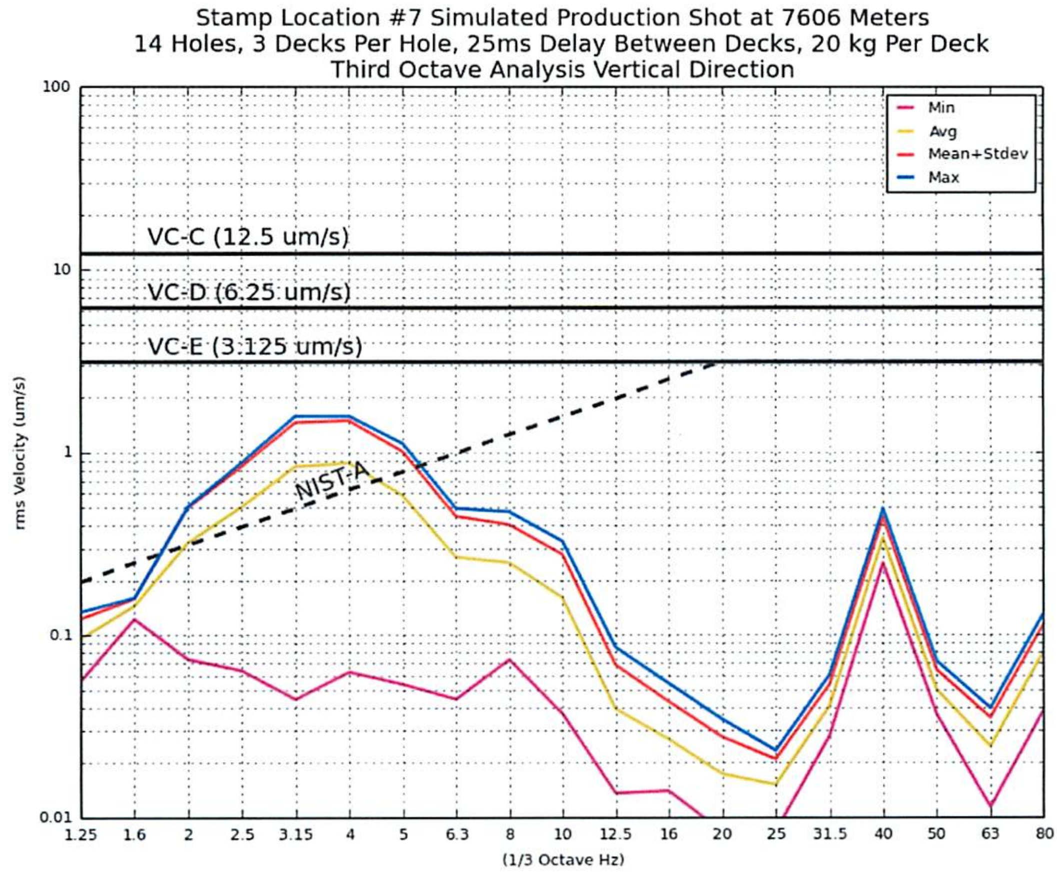
14 Holes, 3 Decks Per Hole, 25 ms Delay Between Decks, 20 kg Per Deck
Time History
Vert Pk=9.0 um/s
Long Pk=9.1 um/s
Tran Pk=6.2 um/s
um/s
sec
10
5
0
−5
−10
6
4
2
−2
−4
−6
−8
8
12
14
16

Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 25 ms Delay Between Decks, 20 kg Per Deck
Narrow Band Spectrum Hann Window 80% Overlap (df=0.125 Hz)




Stamp Location #7 Simulated Production Shot at 7606 Meters
14 Holes, 3 Decks Per Hole, 25ms Delay Between Decks, 20 kg Per Deck
Third Octave Analysis Vertical Direction
Min
Avg
Mean+Stdev
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NIST-A
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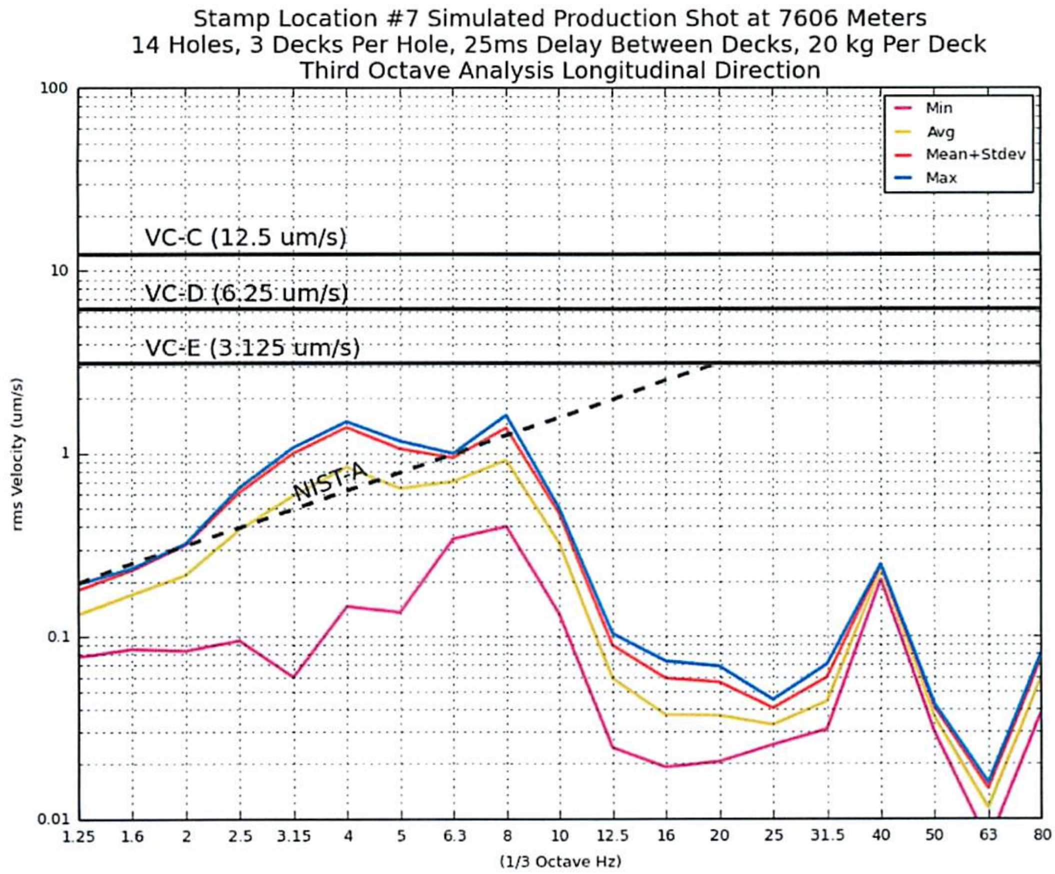
(1/3 Octave Hz)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rms Velocity (um/s)
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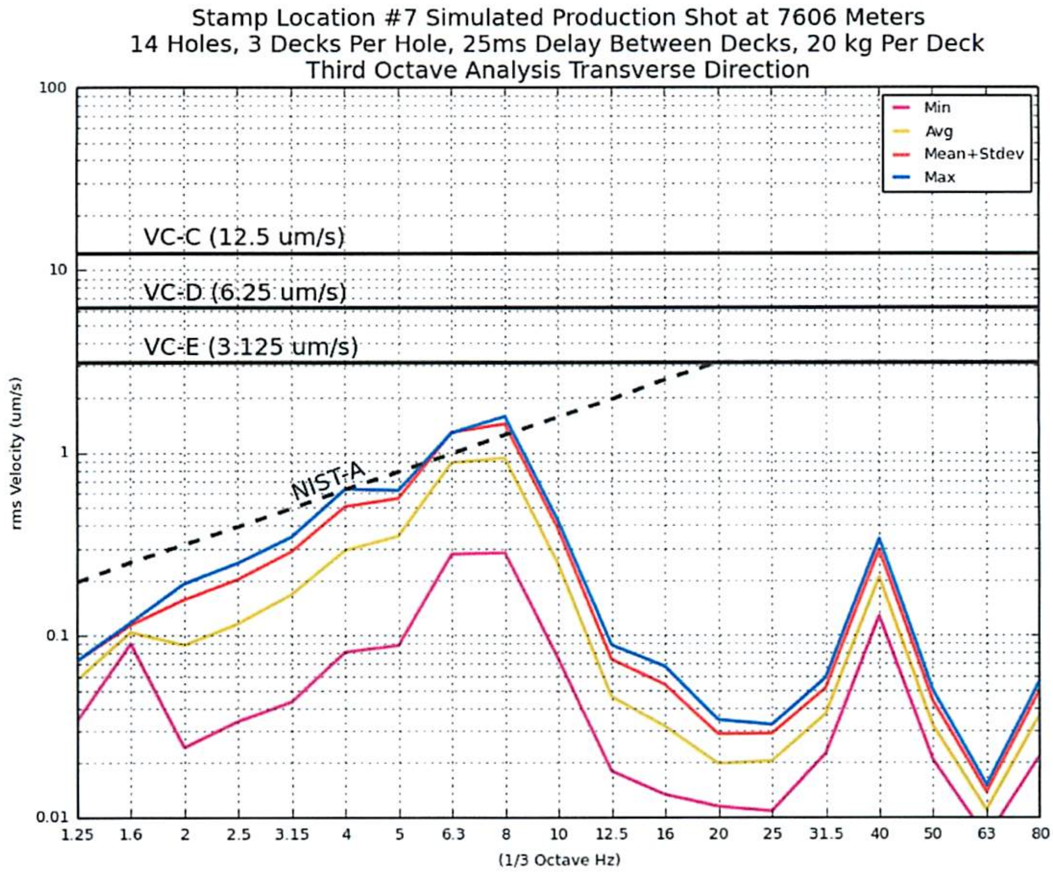
(1/3 Octave Hz)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Third Octave Analysis Transverse Direction
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VC-D (6.25 um/s)
VC-E (3.125 um/s)
NIST-A
rms Velocity (um/s)
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12.5
16
20
25
31.5
40
50
63
80
(1/3 Octave Hz)

9 Conclusion

The results of the Colin Gordon September 2012 ambient vibration study show that the ambient vibration levels at the STAMP property are extremely low meeting both the NIST-A and VC-E vibration criteria. This level of ambient vibration is due to the remote nature of the site. Vibra-Tech Engineers ambient vibration measurements were consistent with the past measurements.

The quarry has four (4) phased areas of rock removal planned. Phase I is the closest proposed quarry area to the STAMP property. The proposed quarry boundary for Phase 1 ranges from approximately 7,606 meters (4.7 miles) to 7,940 meters (4.93 miles) from the closest STAMP location.

Based on the analysis of the collected data and the closest blasting distance of 7,606 meters (4.7 miles) production blast plans have been developed to limit ground vibrations at the STAMP induced by quarry blasting to meet the very restrictive VC-E vibration criteria, and the most restrictive NIST-A criteria.

Predictions show that the VC-E and NIST-A criteria could be met at the closest distance of 7,606 meters if the production shot was limited to 20 kg (44 lbs.) of explosives per deck. A fourteen (14) hole blast consisting of 101.6 mm (4 inch) diameter holes with 3 explosive decks/hole would achieve this objective. This production blast would yield approximately 6,888 tons of material.

Blast simulations indicate that maximum destructive interference between the seismic waves will occur at 72 ms between explosive charges. The results of blast simulations are reported for 25 ms, 50 ms and 72 ms delays between the decks. The resulting surface wave at the STAMP area will have an envelope of approximately 8 seconds. After 8 seconds the ground vibration at the STAMP property will return to the ambient conditions.

It should be noted that all blast designs and explosive simulations in this report are based on seismic data collected from a highly confined single-hole blast. Once the pit is developed and free faces exist for production blasting operations, an adjustment in delays and maximum explosive charge per delay may be possible based upon ongoing seismic recordings.