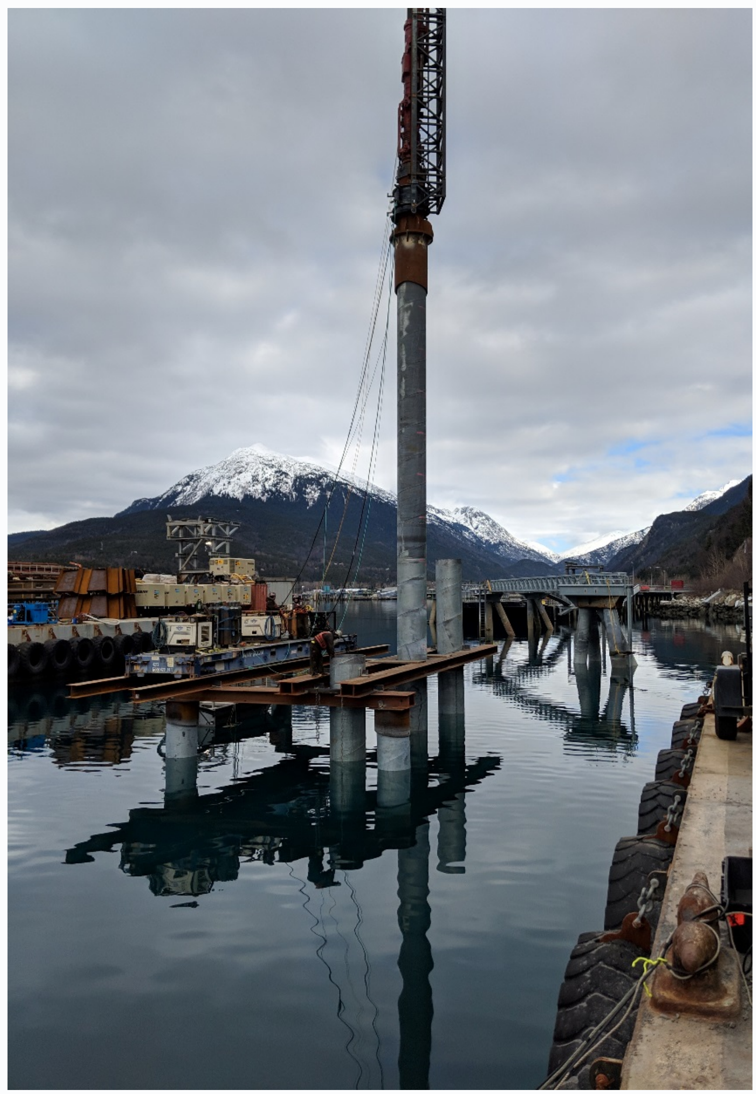
WHITE PASS &YUKON RAILROAD MOORING DOLPHIN INSTALLATION

PILE DRIVING AND DRILLING SOUND SOURCE VERIFICATION

Skagway, Alaska

May 2019
Updated November 22, 2019



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Introduction

White Pass & Yukon Route (WP&YR) is installing two new 200-ton pile supported mooring dolphins at the south end of the company's Railroad Dock (RR Dock) to accommodate an increased number of large cruise ships. Each dolphin consists of six 42-inch diameter steel pipe piles up to 300-feet in length. Temporary support piles (i.e. template piles) for pile driving were also installed to aid with construction and will be removed after the permanent dolphin piles have been installed. Temporary support piles were to include 14, 36-inch in diameter steel piles. Installation of the temporary support and dolphin piles combined three methods: vibratory pile driving, impact pile driving, and rock socket drilling. Temporary pile extraction will only be performed with a vibratory hammer.

The aft berth of the dock is located at the southeast end of town at the terminus of Congress Way and the WP&YR rail tracks (*Figure 1*). This sound source verification (SSV) consisted of the measurement of underwater sounds at distances of 10 meters to 7 kilometers from the pile driving construction and 10 meters to 2 kilometers from the rock socket drilling construction. Both construction activities were performed on 42-inch diameter, steel piles (MD4 and MD5).

Figure 1. Location of dolphin pile installation at terminus of WP&YR rail tracks at the end of the existing pier.

Terminology

Terms

Various technical terms used in this report are defined in the Glossary of Terms in *Appendix A*. Sound pressure is the instantaneous absolute positive or negative pressure and is presented in this report as a decibel referenced as 1 micro Pascal (dB re 1 μPa). While several noise metrics are used to describe sounds in the environment, the root-mean-square (RMS) sound pressure level is an appropriate descriptor to describe measured sounds from continuous and impulsive sounds but with different averaging time constants. The RMS sound pressure level is presented in dB re 1 μPa and is averaged over a defined time period in a stated frequency range or band. The appropriate time period to average for the RMS computation varies by the type of sound (e.g., pulsed or continuous). The average sound level during the measurement period is also computed to be the equivalent average sound pressure level (L_{eq}). Sound Exposure Level (SEL) is proportionally equivalent to the time integral of the pressure squared and is also described in this report in terms of dB re 1 μPa^2 sec over the duration of a sound event. Sounds were measured over the frequency range of 20 to 20,000 hertz (Hz).

Sound Types

There were continuous and impulsive sounds measured during this SSV. The definition between an Impulsive and a Continuous sound is not clear. Distinct sounds that last less than 1 second, such as acoustic pulses from pile strikes, are clearly impulsive. Where more steady-state sounds, such as those from vibratory pile driving, are considered continuous sounds. This project included drilling sounds that would be considered continuous; however, they included sounds from rock hammering. The rock hammering is impulsive but occurs rapidly and is somewhat masked by the lower amplitude drilling sounds. As shown in this report, the pulses are considerably above the continuous drilling sounds. They occur in rapid succession, at a repetitive rate of about 10 Hz. There is no specific definition of the repetition rate that defines a continuous sound or vice versa. It should be noted that ANSI S12.9-2005/Part4 states that highly impulsive sounds occurring at a rate greater than about 20 per second would not be perceived as distinct impulses.[1] The type of sound is judge at the receiver and not the source.

Reference Pressure

All decibels reported are referenced to 1 μPa for peak pressures and RMS (or L_{eq}) levels. SEL is reported in dB referenced to 1 μPa^2 sec.

[1] ANSI. 2005. Quantities and Procedures for Description and Measurement of Environmental Sound – Part 4: Noise Assessment and Prediction of Long-term Community Response.

Equipment and Methods

Equipment

Two methods were used to collect underwater sound measurements at various positions in relation to the piles. An autonomous unit equipped with a hydrophone, signal processing equipment, and a digital audio recorder was left unattended. This unit was attached to the construciton barge or existing dock facilties near construciton activities and suspended to a depth of 20 meters. The autonomous unit consisted of a RESON TC4013 hydrophone with PCB in-line charge amplifier (Model 422E13), PCB Multi Gain Signal Conditioner (Model 480M122), and two Roland Model R-05 Solid State Recorders (*Figure 2*). The Roland recorders were set to a sampling rate of at least 48,000 samples per second. These units were deployed on all days of monitoring.

Figure 2. Autonomous and live hydrophone systems.

Live measurements were made at the barge in the near-field, from dock facilities (see *Figure 2*) and from a small aluminum vessel in the far-field. Hydrophones were deployed at depths ranging from 5 to 30 meters. The far-field vessel and hydrophones were drifting while all measurements were made so that strumming vibrations were minimized. These live measurements were made using RESON Model TC-4033 hydrophones. At each location, two methods were used to process the signal. The first method, which was utilized with the deep hydrophone at the barge and the shallow hydrophone on the vessel, consisted of feeding the hydrophone signal directly into a Larson Davis Model 831 Precision Sound Level Meter (LDL 831). The second method, which was utilized with the shallow hydrophone at the barge and the deep hydrophone on the vessel, consisted of feeding the hydrophone signal through an in-line PCB Model 422E13 charge converter and into a PCB Model 480M122 Power Supply. The output was then split into a LDL 831 and a Roland R-05 solid-state digital data recorder. Live measurements were made on all days of monitoring.

Pile driving sound recordings were analyzed in real-time using the LDL 831. Sound recordings of rock socket drilling were further processed with Astro-Med, Inc. TMX multi-channel data acquisition systems to capture several pulses within a short period of time. These data and impact pile driving sound recordings were then analyzed through a LabVIEW program for the computation of pulse-specific sound metrics.

All data were analyzed in 1/3rd octave bands between 20 Hz and 2 kHz. A Fast Fourier Transform (FFT) was performed on a one-minute representative sample of the rock socket drilling data using the FFT mode in the LDL 831 with a fixed bandwidth of 3.125 Hz. A Power Spectral Density (PSD) was then computed.

Piles Measured

Pile driving measurements were made for Railroad Dock Mooring Dolphins 4 and 5. Each dolphin consisted of one 42-inch diameter steel vertical pile and three battered piles (3:1) with the same diameter. Pile installation log sheets are provided in *Appendix B.*

Piles associated with Mooring Dolphin 5 (MD5) were driven in water that was about 120 feet deep. All vibratory SSV measurements and the first set of impact pile driving SSV measurements were made for the vertical MD5 Pile. Vibratory and impact pile driving drove this pile to about 54 feet deep into the substrate. However, the SSV measurements were made after intermittent vibratory pile driving was conducted over the previous several days to ensure an appropriate SSV sample was taken that reflected the hardest driving conditions and that measurements from appropriate far-field positions could be accommodated. Rock socket measurements were also made, where the pile was installed to a final elevation that was 10 feet deeper. Note rock socket measurements occurred during the first two feet of the pile drilling.

Impact driving and rock socket drilling measurements were made for Pile MD4-V. This pile was installed in about 115 feet of water and was driven to a depth 50 feet deeper. Rock socket measurements were also conducted for this pile where the final elevation was 7 feet deeper.

Rock anchor drilling was measured for the three battered piles associated with MD4, primarily MD4-southeast, where much of the drilling/hammering occurred. Socket lengths were 10 to 18 feet deep.

Note that rock anchor casing installation was measured for each of these piles, where a pneumatic hammer was used to drive each casing for about one minute each.

Pile Driving Measurements

Figure 3. Vibratory hammer on pile.

All pile driving measurements, both vibratory and impact driving, were made on the morning of Friday, March 8th, 2019. These measurements were conducted under calm winds, slow currents, and minimal wave height during the pile driving measurement period. Note that no ships were in port during any of the measurements and there was little or no boat traffic in the inlet.

Vibratory Pile Installation. All vibratory pile driving occurred on a 42-inch steel pile (MD5-V). Since most of the vibratory driving was complete, the Contractor drove the pile for four 5-minute intervals (these are referred to as "events"), such that measurements could be made at a variety of far-field positions. Measurements of vibratory driving were made from 10 meters to nearly 7 kilometers. The autonomous unit was deployed 100 meters northeast of pile MD5-V from an existing pier structure. The near-field live hydrophones were deployed from an anchored barge, 10 meters southeast of pile MD5-V. The attended far-field live system ranged from 100 meters west to 7 kilometers southwest of the piles, (*Figure 3*). Far-field measurements were taken while the vessel was drifting for 5-6 minutes to reduce strumming from the hydrophone cables. There was little current, so positioning of the vessel was not an issue during the vibratory driving.

Impact Pile Driving. Pile driving occurred for three intervals: (1) 5 minutes on Pile MDV5-V, (2) one-minute on Pile MD4-V, and (3) one minute also on Pile MD4-V. The pile was installed at a level of refusal (no measurable penetration could occur), so the impact pile driving was conducted to accommodate this SSV. The driving times were limited to avoid damage to the pile or hammer. A drilling shoe was attached to the top of the pile that may have reduced energy imparted to the pile. The first impact pile driving event (5 minutes) occurred on MD5-V, while the second and third events (1 minute each) occurred on MD4-V that was 15 meters to the northeast. Measurements of impact pile driving were made from 10 meters to 3.3 kilometers. The autonomous unit and near-field live hydrophones remained at the same locations as during vibratory pile driving. During the second

Figure 4. Impact hammer on pile MD4-V (note drilling shoe).

and third events, the autonomous unit was 70 meters northeast of pile MD4-V and the near-field live system was 25 meters southeast of pile MD5-V. The far-field live system ranged from 100 meters to 3.3 kilometers southwest of the piles (*Figure 4*). Far-field measurements were taken while the vessel was drifting for 5 minutes during the first event, and 1 minute each during the second and third events to reduce strumming from the hydrophone cables.

Rock Socket Drilling Measurements

Figure 5. Rock socket drilling in pile MD5-V.

Rock socket drilling involved drilling down through substrate consisting of boulders and rock with a drill bit equipped with a down-hole hammer (*Figure 5*). The sounds from this operation cycle through various levels of drilling with intermittent hammering and clean-out of the pile socket. Both continuous and intermittent hammering occurs. The rapid hammering occurs at a frequency of 10-11 Hz.

When rock socket drilling began, a storm moved in with strong wind, fast currents, rough waves, and poor visibility. A combination of adverse weather conditions and construction difficulties delayed rock socket drilling until Monday, March 11th, Tuesday, March 12th, and Wednesday, March 13th. Sea conditions in the inlet were rough during this measurement period, with wind speed ranging from 10-15 m/s (20-30 mph) from the southwest and wave heights of 1 m (2-4 feet).

Measurements on March 11th were made from the dock facilities at 70 meters using the autonomous unit and at 120 meters with the live system. Drilling on March 11th started on pile MD4-V before the live hydrophone monitoring equipment was completely set-up.

Measurements on March 12th did not capture the rock socket hammer operating at full power, as complications with the drilling occurred. Therefore, this data is not included in the report.

Drilling on March 13th took place on pile MD5-V. Due to the spray of the discharge hose, the near-field live system was moved further to the south and both hydrophones were deployed 12 meters from the pile. The autonomous unit was deployed 100 meters to the northeast. The far-field live system was deployed from the vessel at 1.75 kilometers when drilling began. Over the course of 10 minutes, the vessel drifted north to 1.4 kilometers from the pile, (*Figure 6*).

Rock Anchor Drilling Measurements

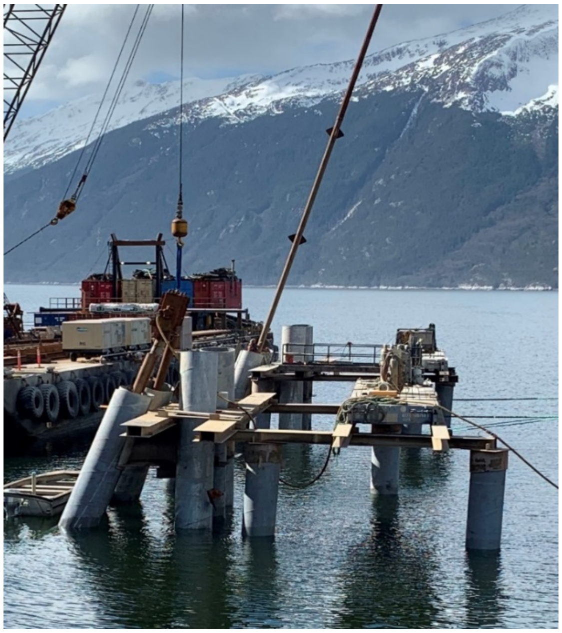

Figure 6. Rock anchor casing installation for pile MD4-NE.

After completion of the rock sockets and clean out, rock anchor drilling occurred. Rock anchor drilling involves setting a casing using a pneumatic air hammer, then a rock anchor drill bit with a down-hole hammer operates within the casing. The rock anchor holes are substantially smaller in diameter and deeper than the rock sockets, and therefore, result in a much lower sound. The sound source is located where hammering occurs well within the substrate. Sounds from this activity include hammering of the casing, drilling and intermittent rock hammering, and clean out of the hole. Like rock-socket drilling, sounds from this operation cycle vary through cycles of drilling with intermittent hammering and clean-out of the hole. Both continuous and intermittent hammering occurs.

Measurements were conducted on April 13th from 20 to 110 meters from the dock facilities for rock anchor drilling at the three battered mooring piles at MD4 (*Figure 7*). Attempts were made to measure at 600 to 1,000 meters from a vessel; however, the signal was difficult to detect above the noise produced by current and hydrophone motion in the water (self-noise).

Figure 7. Rock anchor drilling for pile MD4-NE.

Measurement Positions

Measurement positions for vibratory pile driving, which ranged from 10 meters to 7 kilometers, are depicted in *Figure 8*. Impact pile driving measurements ranged from 10 meters to 3.3 kilometers. These measurement positions are shown in *Figure 9*. Rock socket drilling was measured on three separate days and reported for March 11th and March 13th when down-hole rock hammering was conducted as part of the drilling. These measurement positions are shown in *Figure 10* for March 11th and *Figure 11* for March 13th. Rock anchor drilling was conducted on April 13th at positions of 48 meters to 700 meters for three different piles. Measurement positions are shown in *Figure 12*. Note that these measurement position distances are based on the tip elevation of the pile where the sound source is located.

Measurement Results

Sounds were both measured "Live" and recorded. The live signals were first examined to identify specific levels at various measurement positions and different activities. The peak, SEL, RMS, and pulse duration (in the case of impact pile driving) were identified for all construction activities. Accumulated SEL for each measure event was computed based on the measured sound pressure data. Pulse RMS sound pressure levels were measured through analysis of the recorded sounds using pulse detection software. Weighting factor adjustments, defined by National Marine Fisheries Service (NMFS) (2018), were computed for each of the measured SEL sound levels. These adjustments are applied to the following marine mammal hearing groups: Low-frequency (LF) cetaceans, Mid-frequency (MF) cetaceans, High-frequency (HF) cetaceans, Phocid pinnipeds (underwater), and Otariid pinnipeds (underwater).

This section presents the summary of measured sound levels for each activity: (1) Vibratory Pile Installation, (2) Impact Pile Driving, (3) Rock Socket Drilling, and (4) Rock Anchor Drilling. Note that Rock Socket and Rock Anchor Drilling included drilling and hammering sounds, where the sounds originated from the tip of the pile imbedded in the substrate, as opposed to the pile. Rock Anchor drilling also included the sound of the casings for the rock anchors being installed, which included short periods of impact driving with a pneumatic hammer.

Presentation of Data

The time histories of the continuous 1-second sound pressure levels are provided in *Appendix C*. For vibratory driving, this includes plots of the 1-second RMS level. Impact pile driving and rock socket/anchor drilling time history plots include peak pressure, impulse level (from SLM), and the L_{eq} (1 sec). Similar data are provided for rock socket and rock anchor drilling activities.

The 1/3rd-octave band frequency spectra are provided in *Appendix D*. These frequency spectra are plotted based on the median levels for each 1/3rd-octave band frequency center, as well as the minimum and maximum level measured for each band. These data were obtained from the LD831 sound level meters and are based on the median of the measured1-second levels.

For impact driving, a subsequent pulse analysis was conducted that provided the RMS pulse sound level and corresponding pulse duration for sounds for each pile. These data, along with the maximum peak, single strike SEL levels and accumulated SEL, are provided in *Appendix E*.

A Fast Fourier Transform (FFT) of the impact pile strikes at the close in positions were performed to produce a power spectral density (PSD) that is provided in addition to the 1/3rd octave frequency data. These data are provided in *Appendix F*.

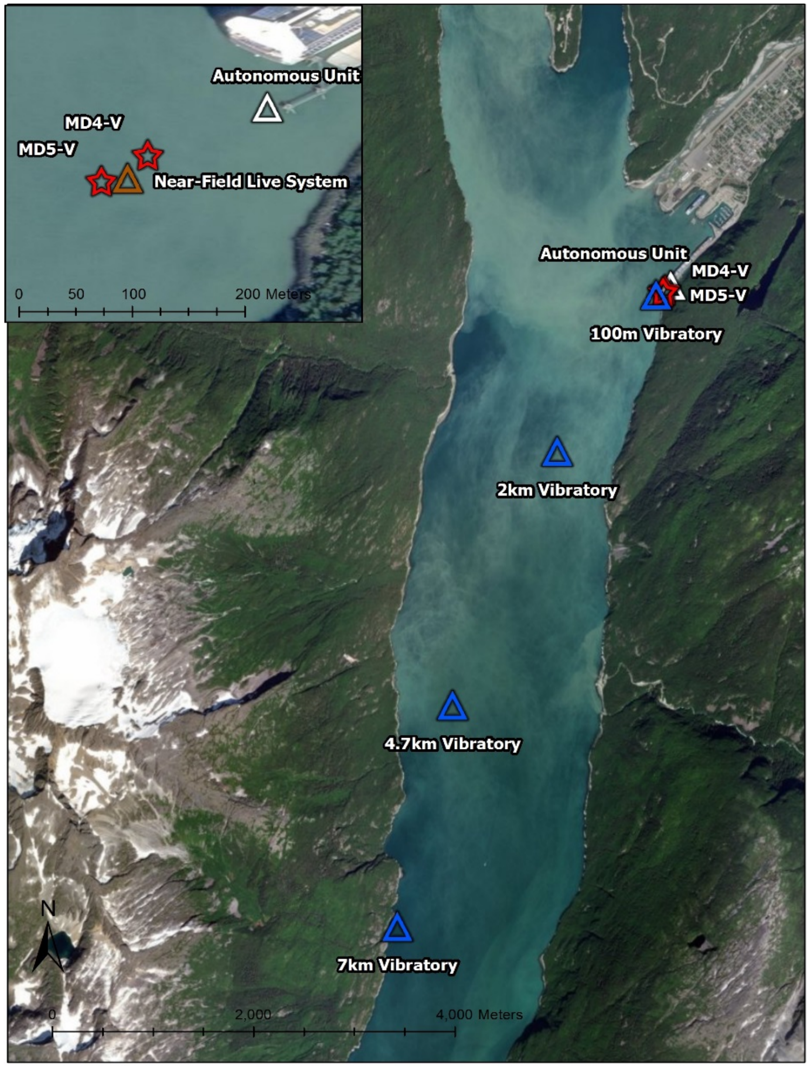

Figure 8. Vibratory pile driving measurement locations in the far-field with an inset of near-field measurements on March 8th, 2019.

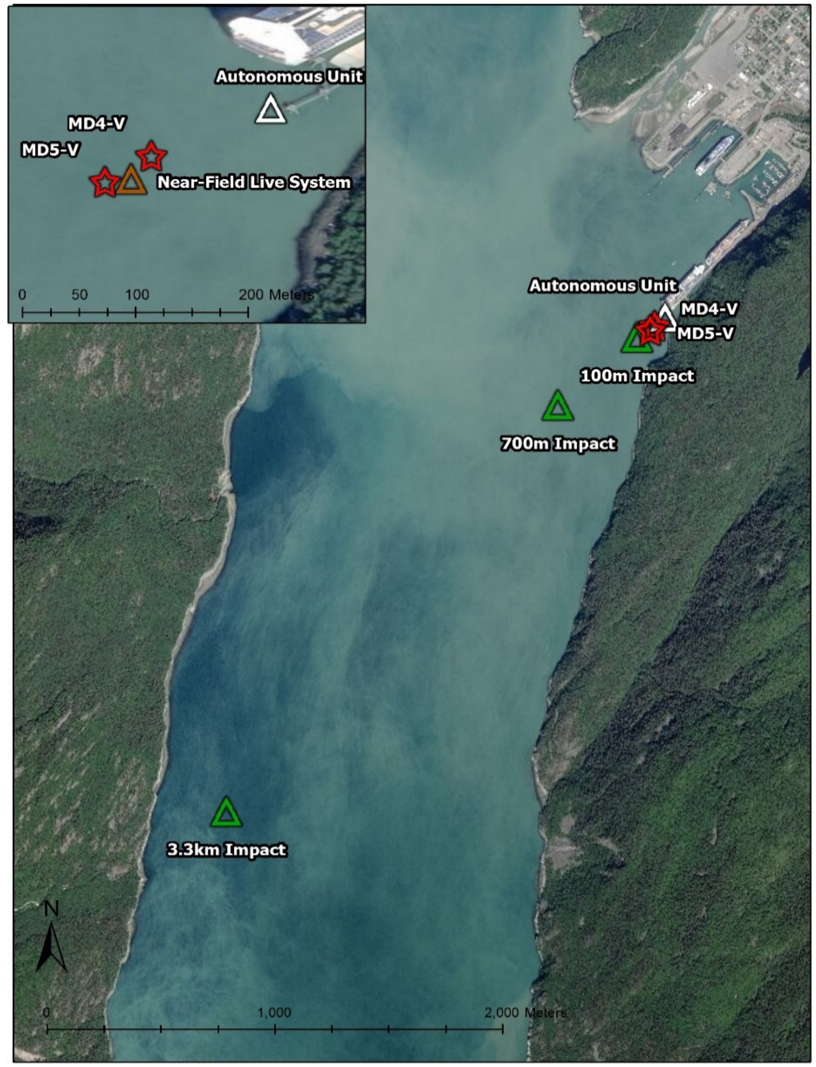

Figure 9. Impact pile driving measurement locations in the far-field with an inset of near-field measurements on March 8th, 2019.

Figure 10. Rock socket drilling measurement locations on March 11th, 2019. The far-field live system was deployed at 120 meters near the end of the docked barge and near-field live system measurements weren't taken on this date. Note that the distance of 120 meters was to the pile, while actual distances to the drilling sound source at the bottom of the pile was 128 meters from the shallow hydrophone and 122 meters from the deep hydrophone.

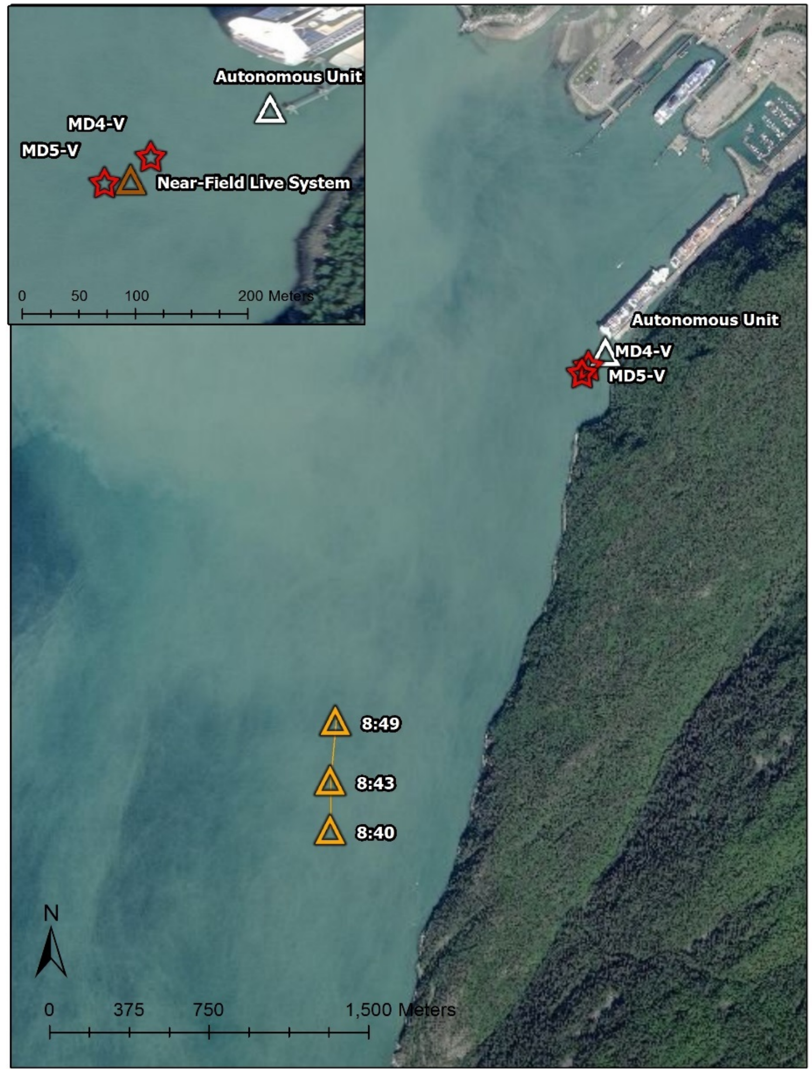

Figure 11. Rock socket drilling measurement locations in the far-field with an inset of near-field measurements on March 13th, 2019. Far-field measurement locations ranged from 1.75 kilometers at 8:40 to 1.4 kilometers at 8:49 due to vessel drift.

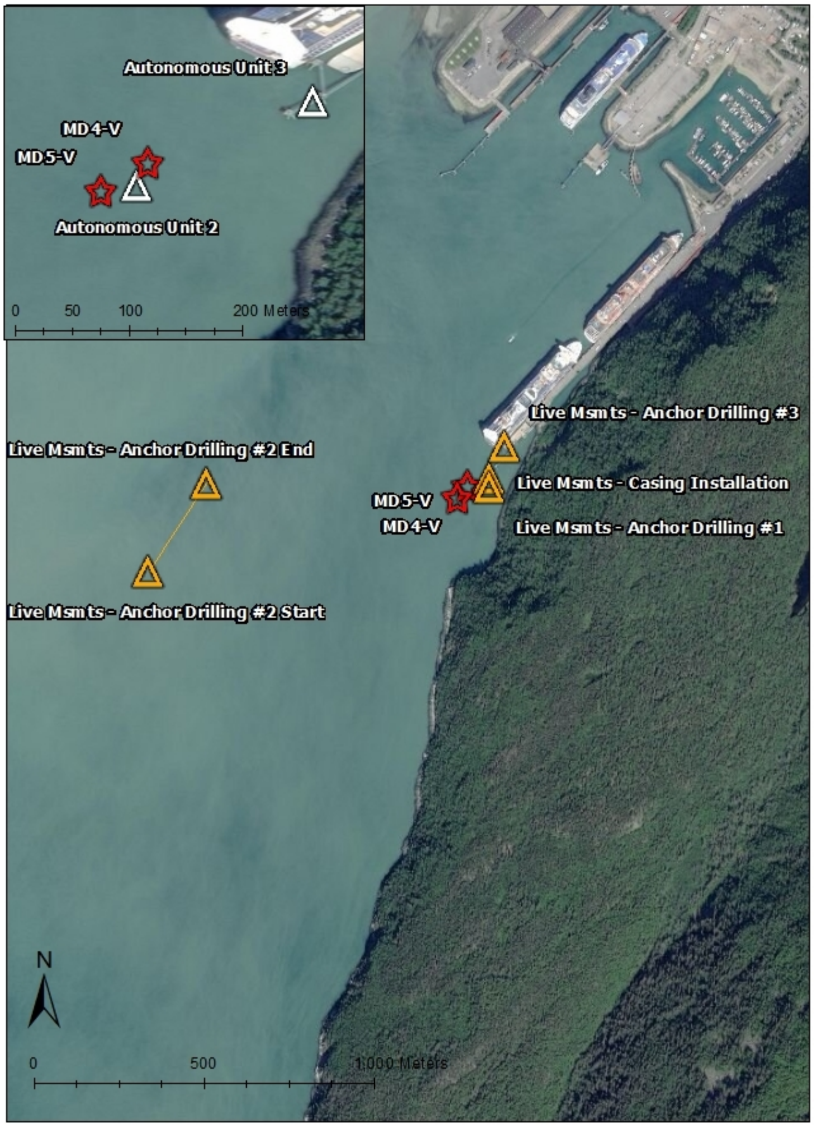

Figure 12. Rock anchor drilling measurement locations on April 13th, 2019. Rock anchor drilling was measured at five positions ranging from 48 to 700 meters, while rock anchor casing installation was measured at one position of 30 meters. Two autonomous units were deployed in the near-field.

Results - Vibratory Pile Driving Measurements

There was a total of four measurement events for vibratory pile driving, which consisted of four intervals of ~5-minute drives. During all events, the near-field live system and the autonomous unit remained at a constant distance and the far-field live system was at 100 meters, 2 kilometers, 4.7 kilometers, and 7 kilometers from pile MD5-V. The summaries of each event are presented in *Table 1*. Sounds generated by vibratory pile driving typically dominated the lower frequency range between 20 and 25 Hz, around 40-80 Hz and from 200 to 4,000 Hz near the source. These same characteristics show up for each vibratory driving event. At greater distances, similar characteristics in the spectra were observed.

Table 1. Summary of vibratory pile driving.

	Near-Field Live		Auto	Far-Field Live	
Event 1, Pile MD5-V 3/8/19 (8:43-8:49)					
Hydrophone Distance	10 m SE		100 m NE	100 m SW	
Hydrophone Depth	30 m	5 m*	20 m	30 m	5 m
RMS(sec) Mean	168	N/A	151	155	156
RMS(sec) Median	168	N/A	151	155	155
RMS (sec) Max	173	N/A	154	158	159
Peak Median	179	N/A	162	165	166
Peak Max.	193	N/A	167	178	179
Duration (sec)	348	N/A	348	348	348
Acc SEL	194	N/A	177	180	181
Event 2, Pile MD5-V 3/8/19 (9:05-9:11)					
Hydrophone Distance	10 m SE		100 m NE	2 km SW	
Hydrophone Depth	30 m	5 m*	20 m	30 m	5 m
RMS(sec) Mean	171	N/A	153	134	134
RMS(sec) Median	170	N/A	153	135	134
RMS (sec) Max	174	N/A	154	137	137
Peak Median	183	N/A	164	145	147
Peak Max.	195	N/A	169	153	150
Duration (sec)	384	N/A	384	384	384
Acc SEL	197	N/A	179	160	160
Event 3, Pile MD5-V3/8/19 (9:56-10:02)					
Hydrophone Distance	10 m SE		100 m NE	4.7 km SW	
Hydrophone Depth	30 m	5 m	20 m	30 m	5 m
RMS(sec) Mean	170	170	152	124	123
RMS(sec) Median	170	171	152	124	123
RMS (sec) Max	173	172	154	126	126
Peak Median	183	185	163	135	141
Peak Max.	195	188	173	141	144
Duration (sec)	350	277	350	350	350
Acc SEL	196	195	178	149	149
Event 4 , Pile MD5-V3/8/19 (10:13-10:18)					
Hydrophone Distance	10 m SE		100 m NE	7 km SW	
Hydrophone Depth	30 m	5 m	20 m	30 m	5 m
RMS(sec) Mean	170	170	151	118	117
RMS(sec) Median	169	169	151	118	116
RMS (sec) Max	173	173	153	122	121
Peak Median	183	183	162	133	141
Peak Max.	194	192	168	140	144
Duration (sec)	280	280	280	280	280
Acc SEL	194	194	175	143	141

*Due to equipment connection issues with the shallow near-field live hydrophone system, events 1 and 2 were not reliably measured.

Sounds generated by vibratory pile driving were typically dominated by relatively broad-band sounds over 50 to 5,000 Hz near the source. The repetition rate of the hammer shows up at 1/3rd-octave band frequencies of 20 to 25 Hz. A similar acoustic signature is evident at the greater distances. *Figure 13* shows the 1/3rd-octave band frequency spectra at varying distance from vibratory driving.

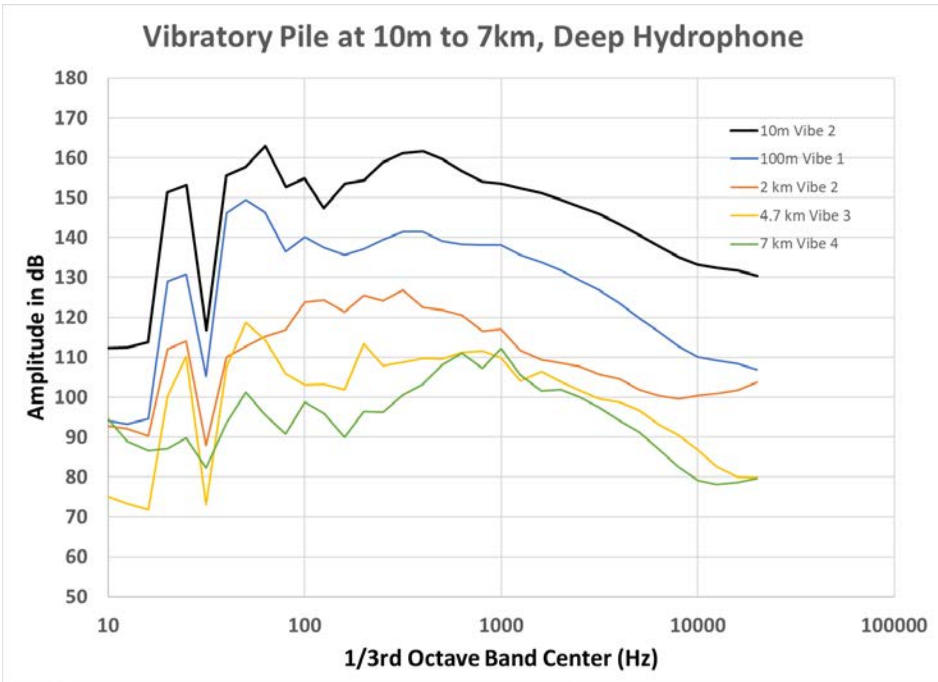

Figure 13. Median 1/3rd octave band sound levels for vibratory pile driving at a range of distances from the pile.

The median 1-second RMS sound level measured at each of the positions was used to develop a regression to compute the source level and transmission loss coefficient in terms of a Log_{10} function. All data were used including data from the deep and shallower hydrophone positions. *Figure 14* depicts the measured fall-off in sound level. The relationship between sound pressure level and distance from the source can be shown by:

$$RL = 186.9 - 17.2 * Log(Distance)$$ from 10 to 6,900 meters

Where, RL = Received RMS Sound Pressure Level at a specified Distance.

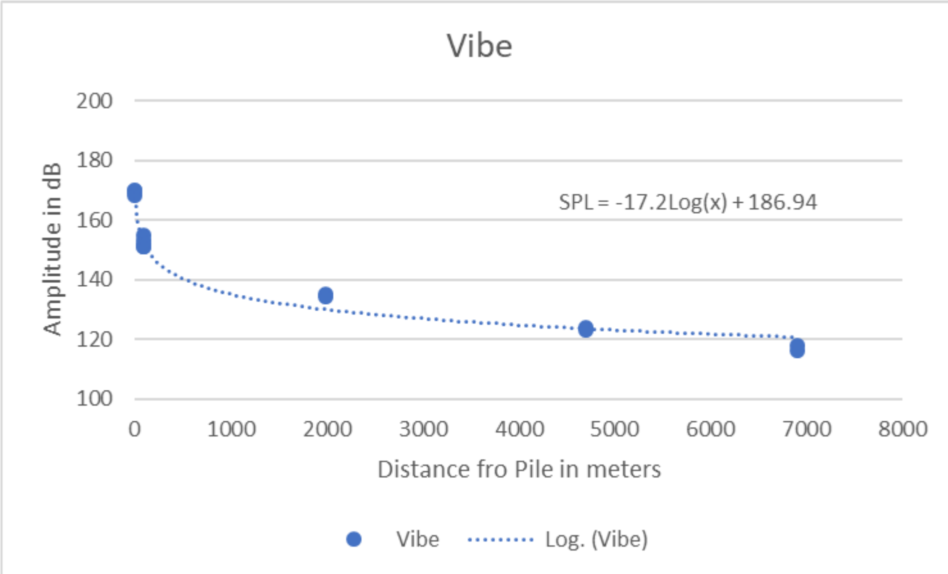

Figure 14. Median sound pressure levels for vibratory pile driving over a range of distances from the pile.

Marine mammal weighting factor adjustments (WFAs) were computed for the five different hearing groups based on the median RMS level reported and the corresponding 1/3rd-octave band spectra. These WFAs are based on guidance provided by NMFS.[2] *Table 2* reports these WFAs. Adjustments to produce these WFAs are described in *Appendix A*. Note that the adjustments to mid and high frequency cetaceans are affected in some of the measurements by the relatively high instrument noise at frequencies above 10,000 Hz. These values are flagged.

Table 2. WFAs based on Median 1-Second RMS for Vibratory Driving (deep/shallow).

Position/Pile Event	LF	MF	HF	Otariid	Phocid
10-m Average	**-2.5**	**-27.4**	**-32.2**	**-13.0**	**-10.9**
10m #1	-4.6/--	-31.0/--	-35.6/--	-13.7/--	-13.7/--
#2	-2.7/--	-28.0/--	-32.2/--	-11.9/--	-11.9/--
#3	-2.9/-1.7	-24.4/-27.2	-28.6/-32.9	-9.5/-9.1	-9.9/-9.5
#4	-3.4/-2.3	-25.7/-28.1	-30.1/-34.0	-9.8/-9.6	-10.3/-10.0
100m #1	-5.3/-4.4	-32.4/-32.1	-37.7/-37.6	-13.9/-13.5	-14.1/-13.6
2km #2*	-2.4/-2.7	-25.9*/-31.8	-28.0*/-36.5	-14.1/-14.3	-13.3/-13.8
4.7km #3	-3.9/-1.6	-27.5/-22.9	-32.4/-27.0	-11.1/-7.0	-11.5/-7.6
7km #4*	-0.5/-0.4	-24.9/-19.6*	-30.2/-22.8*	-6.2/-5.3	-6.8/-5.9

* Affected by high-frequency noise floor.

Impact Pile Driving Measurements

There were three measurement events for impact pile driving, which consisted of three intervals of ~5-minute, 1-minute and 1-minutes. During all events, the near-field live system and the

2 NOAA. 2018. 2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0). April.

autonomous unit remained at the same position, while driving was conducted at two different piles. The far-field live system was at 3.3 kilometers, 100 meters, and 700 meters from the piles. Calculations in the LD831 rely on one-second time intervals to compute metrics and these summaries are presented in *Table 3*. In the field, the Impulse RMS level was used to approximate the pulse RMS level and is reported in Table 3.

Table 3. Summary of impulse time-weighted metrics of impact pile driving over one-second intervals.

	Near-Field Live		**Auto**	**Far-Field Live**	
Event 1, Pile MD5-V 3/8/19 (11:16-11:21)					
Hydrophone Distance	10 m SE		100 m NE	3.3 km SW	
Hydrophone Depth	30 m	5 m	20 m	30 m	5 m
SEL Mean	178	176	159	140	140
SEL Median	179	177	160	141	141
SEL Max	180	179	161	142	142
Impulse RMS Median	192	190	172	148	148
Impulse RMS Max	192	191	171	150	151
Peak Median	206	205	186	160	160
Peak Max	206	205	184	163	161
No. of Strikes	210	210	210	210	210
Acc SEL	202	196	182	161	164
Event 2, Pile MD4-V 3/8/19 (12:02-12:03)					
Hydrophone Distance	25 m SE		70 m NE	100 m SW	
Hydrophone Depth	30 m	5 m	20 m	30 m	5 m
SEL Mean	175	169	162	158	161
SEL Median	176	169	162	159	162
SEL Max	176	170	163	159	163
Impulse RMS Median	189	181	175	172	173
Impulse RMS Max	189	182	175	172	174
Peak Median	202	192	187	184	188
Peak Max	202	193	187	185	189
No. of Strikes	53	53	53	53	53
Acc SEL	192	186	179	175	178
Event 3, Pile MD4-V 3/8/19 (12:12-12:13)					
Hydrophone Distance	25 m SE		70 m NE	700 m SW	
Hydrophone Depth	30 m	5 m	20 m	30 m	5 m
SEL Mean	176	169	162	150	150
SEL Median	176	170	163	151	150
SEL Max	177	170	164	151	151
Impulse RMS Median	189	182	175	163	162
Impulse RMS Max	190	183	175	164	163
Peak Median	202	193	187	177	177
Peak Max	202	194	188	178	178
No. of Strikes	49	49	49	49	48
Acc SEL	192	186	179	167	166

Note that there was a substantial difference (6 to 7 dB) in sound levels measured at the 25-meter position between the two depths of 5 meters and 30 meters. This large difference did not appear for the other positions of 10 meters, 100 meters, 700 meters, and 3.3 kilometers from the pile.

Pile driving sounds are considered impulsive, and therefore, pulse sound metrics are used to describe the RMS sound pressure levels associated with each pulse. Pulse-specific measurements at selected positions are presented in *Table 4*. At close distances, pulses were characterized by distinct elevated acoustical energy concentrated into approximately 0.060–0.080 seconds. With increasing distances, pulse sound pressure decreased while duration increased. Reflections that further increased pulse duration were noted for the measurements at 3.3 kilometers.

The Impulse RMS, using a time constant of 35 milliseconds, provided a fairly reliable estimate of the pulse RMS levels. On average, the Impulse RMS was about 1.8 dB higher than the measured pulse RMS using a fixed time constant.

Sounds generated by impact pile driving were typically dominated by relatively broad-band sounds over 100 to 2,000 Hz, with highest levels around 200 to 400 Hz. A similar acoustic signature is evident at the greater distances, with greater high frequency attenuation above about 2,000 Hz. *Figure15* shows the 1/3rd-octave band frequency spectra at varying distance from impact pile driving.

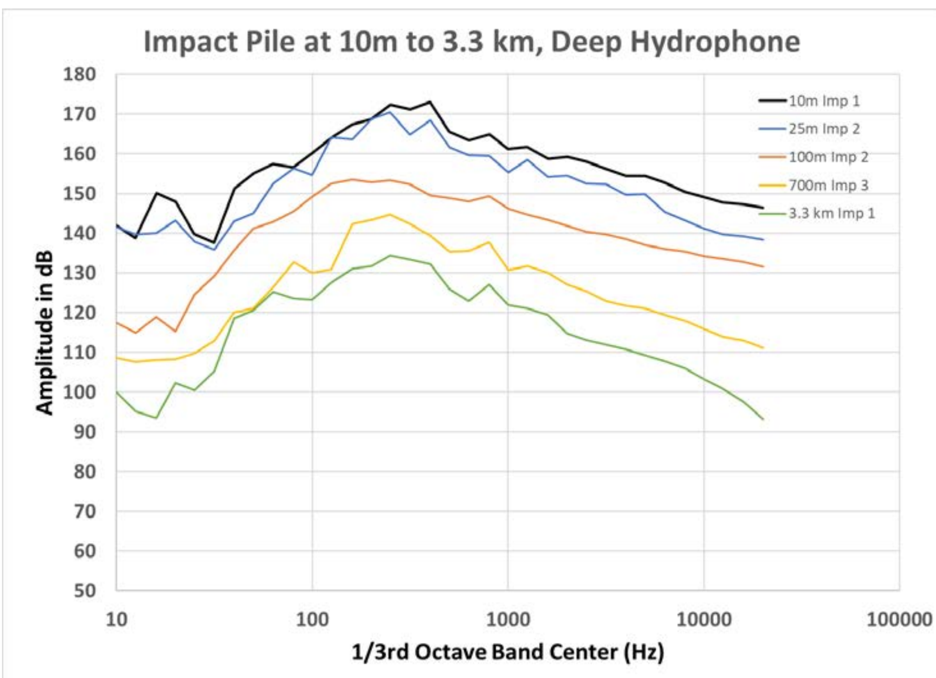

Figure 15. Median 1/3rd octave band sound levels for impact pile driving.

Table 4. Summary of pulse-specific metrics of impact pile driving.

	Near-Field Live	Far-Field Live
Event 1, Pile MD5-V 3/8/19 (11:16-11:21)		
Hydrophone Distance	10 m SE	3.3 km SW
Hydrophone Depth	5 m	30 m
SEL Mean	172	140
SEL Median	176	140
SEL Max	178	147
Pulse RMS Median	188	146
Pulse RMS Max	197	152
Peak Median	204	161
Peak Max.	206	165
Pulse Duration Mean (sec)	0.0718	*>0.2361**
Pulse Duration Median (sec)	0.0621	*>0.2380**
No. of Strikes	148	209
Acc SEL	197	163
Event 2, Pile MD4-V 3/8/19 (12:02-12:03)		
Hydrophone Distance	25 m SE	100 m SW
Hydrophone Depth	5 m	30 m
SEL Mean	169	160
SEL Median	169	161
SEL Max	170	161
Pulse RMS Median	180	170
Pulse RMS Max	181	171
Peak Median	192	183
Peak Max	194	184
Pulse Duration Mean (sec)	0.0744	0.1136
Pulse Duration Median (sec)	0.0720	0.1118
No. of Strikes	53	53
Acc SEL	186	178
Event 3, Pile MD4-V 3/8/19 (12:12-12:13)		
Hydrophone Distance	25 m SE	700 m SW
Hydrophone Depth	5 m	30 m
SEL Mean	169	151
SEL Median	170	151
SEL Max	170	152
Pulse RMS Median	180	161
Pulse RMS Max	181	162
Peak Median	193	177
Peak Max	195	178
Pulse Duration Mean (sec)	0.0749	0.0882
Pulse Duration Median (sec)	0.0754	0.0824
No. of Strikes	49	50
Acc SEL	186	168

The median RMS sound level measured at each of the positions was used to develop a regression to compute the source level and transmission loss coefficient in terms of a Log_{10} function. All data were used including data from the deep and shallower hydrophone positions. *Figure 16* depicts the measured fall-off in sound level. The relationship between sound pressure levels and distance from the source can be shown by:

$$RLpeak = 220 - 16.3 * Log(Distance)_{\textit{from 10 to 3,300 meters}}$$

$$RLrms\ pulse = 206 - 16.6 * Log(Distance)_{\textit{from 10 to 3,300 meters}}$$

$$RLsel = 192 - 15.0 * Log(Distance)_{\textit{from 10 to 3,300 meters}}$$

Where, RL = Received Sound Pressure Level at a specified Distance.

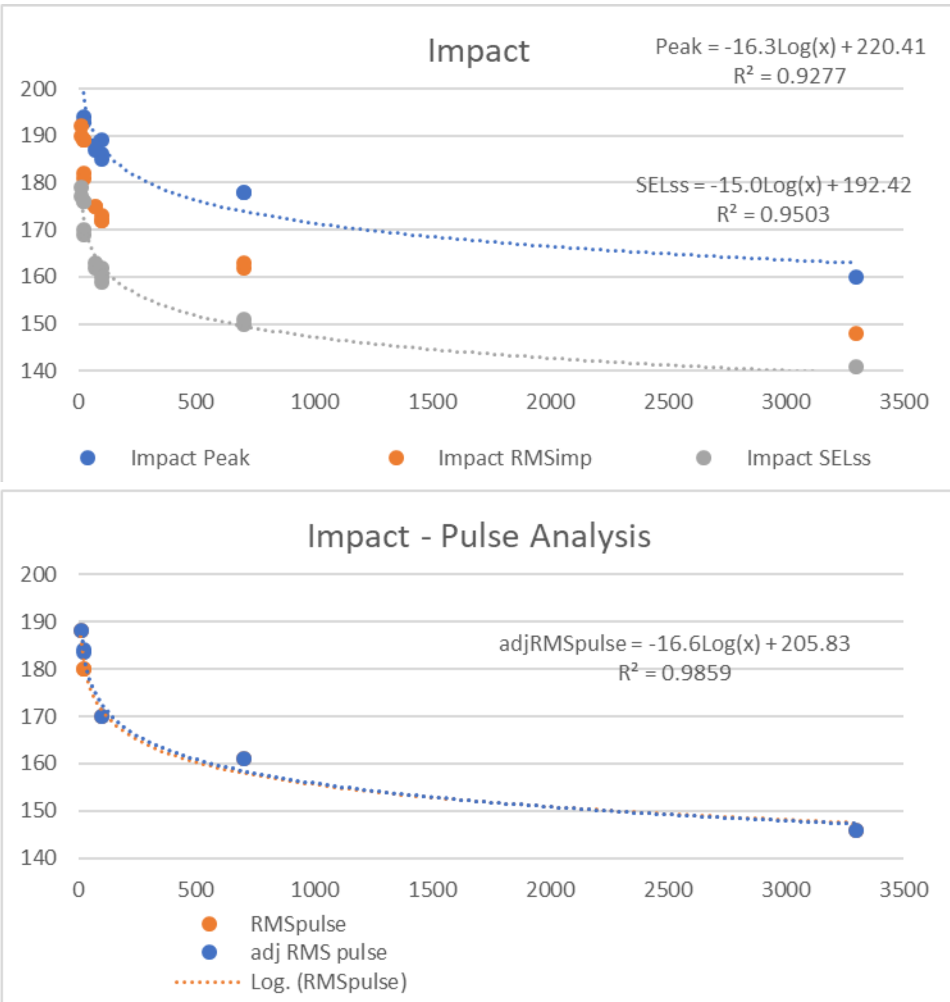

Figure 16. Median sound pressure levels for impact pile driving over a range of distances from the pile. Note that pulse RMS were adjusted to reflect higher levels measured at deeper depths at 25 meters.

Marine mammal WFAs were computed for the five different hearing groups based on the median SEL per strike levels and the corresponding median 1/3rd-octave band spectra. *Table 5* reports WFAs for impact pile driving.

Table 5. WFAs Computed from Median SEL for Impact Driving (deep/shallow).

Position / Pile Event	LF	MF	HF	Otariid	Phocid
10-25m Average	**-1.7**	**-26.0**	**-30.1**	**-10.8**	**-10.7**
10m #1 25m #2 25m #3	-1.4/-1.6 -1.9/-1.7 -1.8/-1.5	-24.5/-23.7 -26.9/-26.4 -27.5/-26.8	-28.9/-26.9 -30.7/-31.3 -31.3/-31.7	-8.5/-11.4 -12.9/-9.1 -13.1/-9.7	-8.9/-11.0 -12.3/-9.5 -12.4/-9.9
3.3 km #1	-2.1/-1.9	-30.8/-29.3	-35.1/-33.4	-14.1/-13.7	-13.2/-12.9
100m #2	-2.0/-2.3	-*31.6*/-21.9	-*37.6*/-24.8	-11.5/-10.9	-11.5/-10.9
700m #3	-2.0/-1.3	--28.3/-27.2	-31.9/-30.9	-13.3/-11.2	-12.7/-10.9

<u>Rock Socket Drilling Measurements</u>

There were two measurement periods of rock socket drilling reported for Pile MD4-V and Pile MD5-V. A summary of this data is presented in *Table 6*.

During the first event on March 11th, 2019, drilling began before all hydrophone equipment could be deployed and there was not enough time to coordinate with vessels to conduct both near- and far-field measurements. The autonomous unit had been deployed 70 meters northeast and one live system was deployed 120 meters northeast during the drilling. The autonomous unit measured 34 minutes of drilling (when most noise occurred), while the live system measured the loudest portion that occurred over 18 minutes.

During the second event on the morning of March 13th, 2019, up to ten minutes of sound was measured before operations were halted. The near-field live system measured this activity at two depths that were 12 meters from the pile (32 meters and 47 meters from the pile tip where sound was generated). The autonomous unit was placed at 76 meters from the pile. The live far-field live system simultaneously measured drilling at about 1.4 kilometers (*Table 4*).

Sounds generated by rock hammering were typically dominated by relatively broad-band sounds over 50 to 4,000 Hz, with highest levels around 100 to 630 Hz. A similar acoustic signature is evident at the greater distances. *Figure 17* shows the 1/3rd-octave band frequency spectra at varying distance from impact pile driving.

Table 6. Summary of rock socket drilling measurements reported in decibels.

	Near-Field Live*		**Auto Full Event**	**Auto Rock Only**	**Far-Field Live* Rock Only**	
Event 1, Pile MD4-V 3/11/19 (16:32-16:50)						
Hydrophone Distance			76m NE	76m NE	122m NE	122m NE
Hydrophone Depth			20 m	20 m	30 m*	5 m*
RMS(sec) Mean			162	164	157	163
RMS(sec) Median			160	163	158	163
RMS (sec) Max			169	169	160	169
Impulse RMS Median			165	167	163	168
Impulse RMS Max			173	173	166	174
Peak Median			177	180	175	184
Peak Max			186	186	179	192
Duration (sec)			2036	1077	26	1068
Acc SEL			195	193	171	194
Event 2, Pile MD5-V 3/13/19 (8:43-8:53)						
Hydrophone Distance	32 m E	47 m E	104 m N		1.4-1.75 km W	
Hydrophone Depth	20 m	5 m	20 m		30 m	5 m
RMS(sec) Mean	173	172	156		144	146
RMS(sec) Median	173	172	156		144	146
RMS (sec) Max	178	177	161		149	151
Impulse RMS Median	178	176	161		149	151
Impulse RMS Max	182	181	165		153	155
Peak Median	193	190	174		162	164
Peak Max	199	194	179		167	169
Duration (sec)	604	603	539		303	311
Acc SEL	201	200	184		169	171

*Event 1 rock socket drilling started before near-field live system equipment was deployed. Only 26 seconds of data was collected with the deep hydrophone.

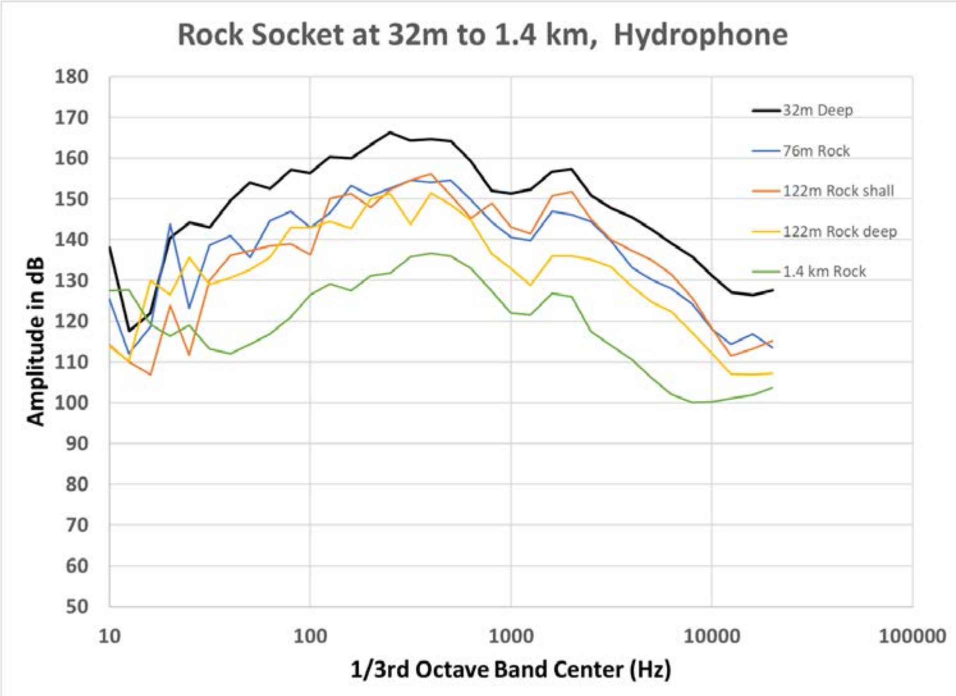

Figure 17. Median 1/3rd octave band sound levels for drilling/hammering at a range of distances from the drill tip.

The median RMS sound level measured at each of the positions was used to develop a regression to compute the source level and transmission loss coefficient in terms of a Log_{10} function. All data were used including data from the deep and shallower hydrophone positions. *Figure 18* depicts the measured fall-off in sound level. The relationship between sound pressure levels and distance from the source can be shown by:

$RLpeak = 219 - 16.7 * Log(Distance)$ from 32 to 1,400 meters

$RLselsec = 195 - 16.2 * Log(Distance)$ from 32 to 1,400 meters

Where, RL = Sound Pressure Level at a specified Distance.

Marine mammal WFAs were computed for the five different hearing groups based on the median RMS level reported and the corresponding 1/3rd-octave band spectra. *Table 7* reports WFAs for rock socket hammering.

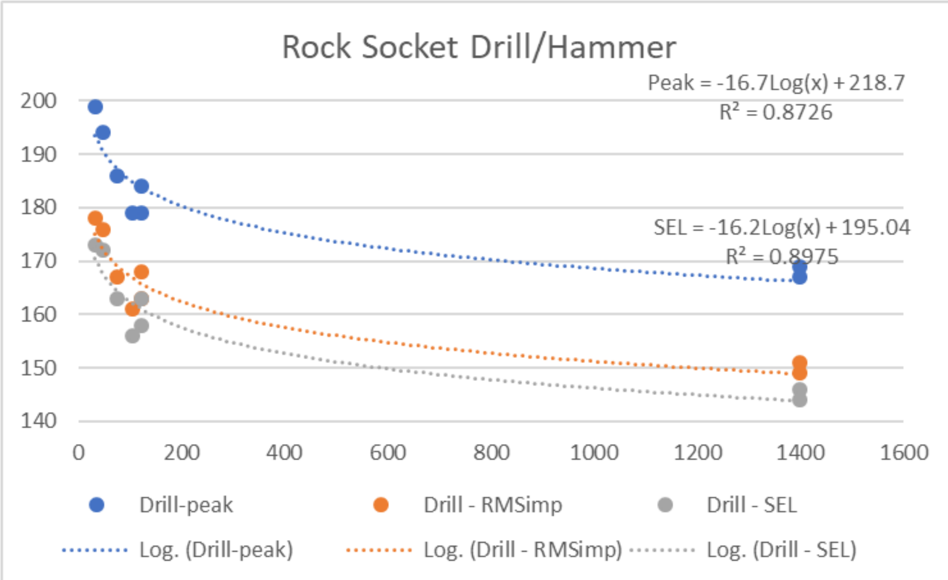

Figure 18. Median sound pressure levels for impact pile driving over a range of distances from the pile.

Table 7. WFAs Computed from Median SEL for Rock Socket (deep/shallow).

Position / Pile Event	LF	MF	HF	Otariid	Phocid
32-47m Average	**-2.1**	**-31.6**	**-37.5**	**-13.5**	**-12.8**
32m #2	-1.8	-29.2	-34.8	-11.5	-11.3
47m #2	-2.5	-34.1	-40.2	-15.6	-14.3
76 m #1	-1.7	-28.7	-34.6	-10.8	-10.7
104m #2	-1.2	-25.9	-32.1	-8.0	-8.4
122m #1	-1.2	-25.6	-31.8	-7.9	-8.3
1.4 km #2	-1.6	-32.9	-39.5	-13.0	-12.2

Rock Anchor Casing Installation Measurements

Rock anchor drilling included sounds from casing installation using a pneumatic hammer, drilling/clean-out, and rock hammering. There were three measurement periods of rock anchor drilling on April 13th, 2019 reported for battered piles associated with Pile MD4. In addition, there were three short period where drill casings were installed using a rapid firing percussion hammer. A summary of this data is presented in *Table 8*.

The unexpected driving of the casings was only measured at 35 and 85 meters. These were fairly short events and was not intended to be part of this SSV. The first two driving events lasted about 5 minutes and the last event was about one and a half minutes. Sound levels associated with the first event were about 10 dB louder than the other events. While similar to pile driving, these sounds were about 5 to over 10 dB quieter.

Table 8. Summary of rock anchor drill casing installation measurements.

	Auto 3 MD4-NE Casing	Auto 3 MD4-East Casing *
Event 1, Pile MD4-NE 4/13/19 (11:20-11:45)		
Hydrophone Distance	85 m	
Hydrophone Depth	20 m	
SEL(sec) Mean	158	
SEL(sec) Median	157	
SEL (sec) Max	162	
Impulse RMS Median	166	
Impulse RMS Max	171	
Peak Median	183	
Peak Max	190	
No. of Seconds	321	
Acc SEL	183	
Event 2, Pile MD4-E 4/13/19 (11:20-11:45)		
Hydrophone Distance	85 m	
Hydrophone Depth	20 m	
SEL(sec) Mean	149	
SEL(sec) Median	149	
SEL (sec) Max	152	
Impulse RMS Median	156	
Impulse RMS Max	160	
Peak Median	169	
Peak Max	176	
No. of Seconds	265	
Acc SEL	173	
Event 3, Pile MD4-SE 4/13/19 (11:20-11:45)		
Hydrophone Distance	85 m	35 m
Hydrophone Depth	20 m	23 m
SEL(sec) Mean	145	152
SEL(sec) Median	149	151
SEL (sec) Max	152	154
Impulse RMS Median	156	158
Impulse RMS Max	158	161
Peak Median	169	171
Peak Max	176	174
No. of Seconds	95	95
Acc SEL	169	172

*Partially shielded by closest pile.

Impact driving of the drill casings produce impulsive sounds. Pulse-specific measurements at selected positions are presented in *Table 9* for the three driving events made at 85 meters and the one event at 35 meters. There were two to three pulses per second, lasting about 0.04 to 0.2 seconds. This large spread in durations depended on the amplitude of the initial portion of the pulse. The sounds at 85 meters were characterized by a fairly sharp peak at the onset of the pulse, which shortened the averaging duration. Where this sharp onset of sound was less, the durations were substantially longer. This peak pressure signature is quite variable, as it is effectively attenuated. Therefore, there was considerable variability from pulse to pulse and for the two different measurement positions. The maximum pulse duration for each event was two to three times that of the average duration.

Sounds generated by impact pile driving were typically dominated by relatively broad-band sounds over 100 to 2,000 Hz, with highest levels around 1,000 to 4,000 Hz. The higher frequency component to these sounds is a factor in the variability of the pulse RMS level and duration. Sounds with the high frequency amplitudes tended to have a shorter duration where 90-percent of the energy was contained. The first drive (measured at 85 meters) had substantially higher levels with distinct higher levels at 1,000 to 10,000 Hz. Driving of the casings produces sounds with much higher frequency content than impact pile driving.

Figure 19 shows the 1/3rd-octave band frequency spectra at varying distance from impact pile driving.

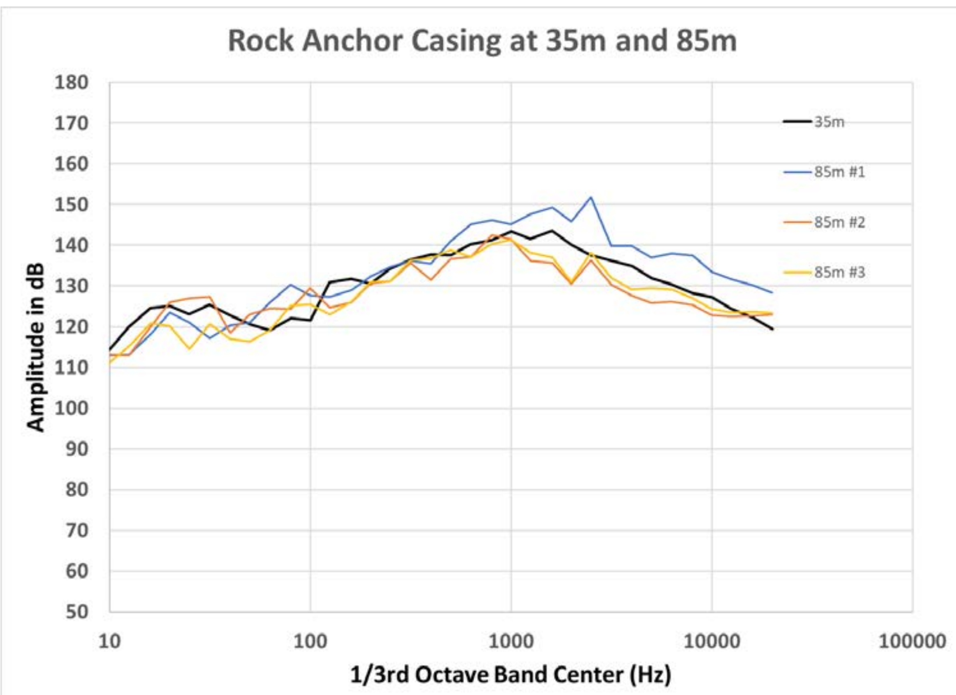

Figure 19. Median 1/3rd octave band sound levels for 1 second of impact driving of drilling casings at 35 and 85 meters from casing.

Table 9. Summary of pulse-specific metrics of impact casing driving.

	Auto 3	**Live System**
Casing for Pile MD4-NE 4/13/19 (11:20-11:45)		
Hydrophone Distance	85 m	
Hydrophone Depth	20 m	
SEL Mean	151.	
SEL Median	152	
SEL Range	139-157	
Pulse RMS Median	164	
Pulse RMS Range	147-171	
Peak Median	181	
Peak Range	163-189	
Pulse Duration Mean (sec)	0.0621	
Pulse Duration Median (sec)	0.0550	
Duration Range	0.03 – 0.15	
No. of Strikes	1093	
Acc SEL	183	
Casing for Pile MD4-East		
SEL Mean	144	
SEL Median	144	
SEL Range	140-148	
Pulse RMS Median	154	
Pulse RMS Range	149-159	
Peak Median	168	
Peak Range	163-174	
Pulse Duration Mean (sec)	0.0952	
Pulse Duration Median (sec)	0.0955	
Duration Range	0.06 – 0.15	
No. of Strikes	723	
Acc SEL	183	
Casing for Pile MD4-SE		
Hydrophone Distance	85 m	35 m
Hydrophone Depth	20 m	23 m
SEL Mean	144	146
SEL Median	145	146
SEL Range	139-147	145-146
Pulse RMS Median	155	151
Pulse RMS Range	149-158	150-151
Peak Median	168	160
Peak Range	163-171	160-161
Pulse Duration Mean (sec)	0.0896	0.2810
Pulse Duration Median (sec)	0.0858	0.2816
Duration Range	0.06 – 0.14	0.27 - 0.29
No. of Strikes	241	133
Acc SEL	184	167

The measurements conducted for the anchor casing installation were not sufficient to develop a source level and sound transmission coefficient to relate received sound level to distance from the drilling casing. Measurements were made at only two positions that were relatively close to the drill casings that were being installed. As a result, these measurement data cannot be used to develop a reliable source level and distance transmission loss coefficients using measurement data for various distances. Assuming the practical spreading loss used in the NMFS Guidance Calculator of *15* Log(Distance from source)*, the median levels at 10 meters would be:

- Peak would be 182 - 195 dB,
- RMSpulse would be 168 to 178 dB, and
- SEL would be about 158 to 166 dB.

These levels were about 5 to 20 dB lower than impact pile driving.

Marine mammal WFAs were computed for the five different hearing groups based on the median RMS level reported and the corresponding 1/3rd-octave band spectra. *Table 10* reports WFAs for rock socket hammering. Note that the higher frequency sounds produced by driving of the casings resulted in less adjustments.

Table 10. WFAs Computed from Median SEL for Rock Socket Casing Driving.

Position / Pile Event	LF	MF	HF	Otariid	Phocid
	-0.5	**-17.2**	**-20.8**	**-4.0**	**-4.7**
85m #1	-0.2	-15.9	-19.9	-2.2	-3.0
85m #2	-0.5	-18.1	-21.1	-5.2	-5.8
85m #3	-0.5	-16.9	-20.1	-4.7	-5.3
35m #3	-0.4	-17.8	-21.9	-3.8	-4.5

Rock Anchor Drilling Measurements

Rock anchor drilling included sounds from drilling/clean-out and rock hammering. There were three measurement periods of rock anchor drilling on April 13th, 2019 for the battered piles, MD4-NE, MD4-E and MD-SE. Drilling using the rock anchor appears to be most pronounced during the 3rd driving event. Based on examination of the data, it appears the rock hammer was not used during the second event.

Measurements of the first period occurred at distances of 22, 27 and 85 meters from the pile. Note these distances are referenced to pile but the drill/hammer position within the substrate was the source of sound during these events. For the first event, these were computed as 37, 40, and 88 meters from the drill tip. Measurements for the second period were made at distances of 20, 85, and about 700 meters from the pile or approximately 36, 40, and 89 meters from the drill tip. The third, and most representative rock anchor drilling event, was measured at distances of 19, 85, and 110 meters from the pile, which were computed as 36, 91, 116, and 122 meters from the drill tip. *Table 11* reports these results.

Table 11. Summary of rock anchor drilling measurements.

	Auto 2	Auto 3	Live System	
Event 1, Pile MD4-NE 4/13/19 (14:29-14:50)				
Hydrophone Distance	37 m	88 m	40 m	N/A
Hydrophone Depth	23 m	20 m	23 m	N/A
RMS Mean	142	133	139	N/A
RMS Median	138	128	135	N/A
RMS Max	153	141	147	N/A
Impulse RMS Median	142	131	139	N/A
Impulse RMS Max	156	144	151	N/A
Peak Median	153	143	147	N/A
Peak Max	169	155	162	N/A
Duration (sec)	1299	1299	1299	N/A
Acc SEL	171	157	169	N/A
Event 2, Pile MD4-E 4/13/19 (15:30-15:49)				
Hydrophone Distance	36 m	89 m	600 - 700 m	
Hydrophone Depth	23 m	20 m	23 m	5 m
RMS Mean	142	127	110	109
RMS Median	140	123	106	104
RMS Max	154	135	129*	127*
Impulse RMS Median	145	127	129*	134*
Impulse RMS Max	161	142	137*	144*
Peak Median	158	<140	133*	137*
Peak Max	179	154	145*	150*
Duration (sec)	772	772	772	772
Acc SEL	171	151	137	134
Event 3, Pile MD4-SE 4/13/19 (17:59-18:59)				
Hydrophone Distance	36 m	91 m	116 m	122 m
Hydrophone Depth	23 m	20 m	23 m	5 m
RMS Mean	149	136	133	130
RMS Median	148	135	131	128
RMS Max	158	142	138	135
Impulse RMS Median	151	137	134	131
Impulse RMS Max	161	146	141	140
Peak Median	160	147	142	141
Peak Max	170	159	155	152
Duration (sec)	2194	2194	2194	2194
Acc SEL	182	168	164	160

*Due to the influence of weather conditions, there was interference at very low frequencies. This interference cannot be removed from one-second interval metrics calculated by the LD 831. All other calculations presented at this distance were performed on a frequency range of 80-20,000 Hz.

These sounds are difficult to characterize due to the relatively low amplitude, variability of the activity and the location of the sound source that is embedded in the substrate. There were multiple sources in the vicinity of the pile. These sources were less pronounced at distances beyond about 40 meters.

The sounds from rock anchor drilling (includes drilling, rock hammering, and clean out) were about 20 dB quieter than the sounds from rock socket drilling and 15 dB lower than vibratory installation sounds. Maximum continuous RMS levels were about 135 dB at 100 meters.

Examination of the 1/3rd octave band spectra indicates that the loudest sounds from this activity were over the range of 20 to 4,000 Hz. Note that sounds from this activity vary with the highest amplitude sounds occurring during hammering. Higher frequency sounds occur during drilling and clean out. *Figure 20* shows the 1/3rd-octave band frequency spectra for rock anchor drilling sounds during the third drilling event. This event lasted the longest and produced the highest sound levels.

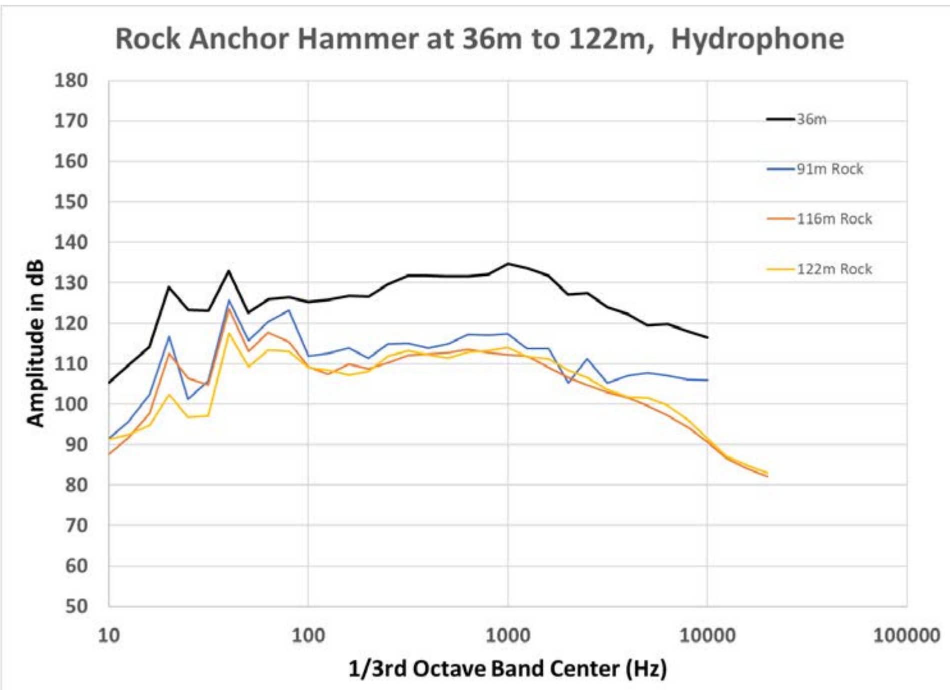

Figure 20. Median 1/3rd octave band sound levels for Pile MD4-SE anchor drilling/hammering at a range of distances from the pile.

The median RMS sound level measured at each of the positions was used to develop a regression to compute the source level and transmission loss coefficient in terms of a Log10 function. All data were used including data from the deep and shallower hydrophone positions. *Figure 21* depicts the measured fall-off in sound level for all of the events and for just the third drilling event that had the highest sound levels and clearly used the rock hammer. This event was about 8 to 10 dB louder than the other events. The range in relationship between sound pressure levels and distance from the source for all drilling can be shown by:

$$RLrms\ cont = 185 - 28.1 * Log(Distance)$$ from 36 to 600 meters

The relationship for just the 3rd, and most representative event, can be shown as:

$$RLrms\ cont = 203 - 35.4 * Log(Distance)$$ from 36 to 122 meters

Where RL = Received RMS Sound Pressure Level at a specified Distance.

Marine mammal WFAs were computed for the five different hearing groups based on the median RMS level reported and the corresponding 1/3rd-octave band spectra. *Table 12* reports WFAs for rock socket hammering.

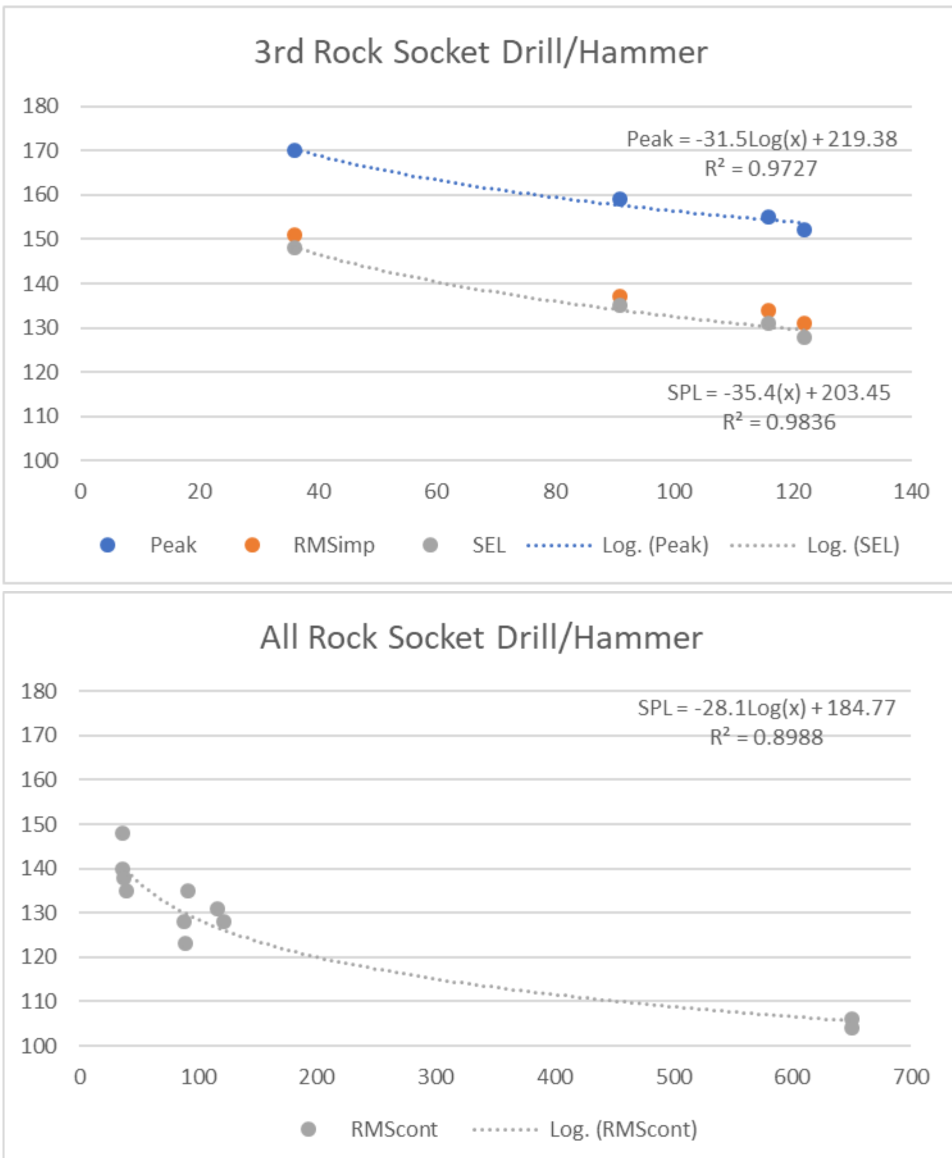

Figure 21. Median sound pressure levels for rock anchor drilling (all drilling events and only the 3rd event).

Table 7. WFAs Computed from Median SEL for Rock Anchor Drilling (deep/shallow)

Position / Pile Event		LF	MF	HF	Otariid	Phocid
36-40m Average		**-3.8**	**-21.1**	**-23.6**	**-10.5**	**-10.8**
37m	#1	-4.5	-21.9	24.2	-11.2	-11.6
40m	#1	-5.5	-21.8	-24.0	-13.8	-13.7
80m	#1	--*	--*	--*	--*	--*
36m	#3	-1.5	-19.7	-22.6	-6.4	-7.0
91m	#3	-4.7	-17.9	-20.0	-10.4	-10.7
116m	#3	-5.0/-2.5	-27.9-24.0	-32.6/-28.8	-11.7-8.3	-12.2-8.8

*High frequency instrument background contributed to measured sounds.

Ambient Conditions

An ambient survey of underwater sound was not conducted for the Taiya Inlet as part of this SSV. However, measurements conducted during this survey provide information regarding ambient sound conditions. During this SSV, there was little vessel traffic. Measurements made on March 8th, 2019were conducted when there was no vessel traffic under calm conditions with little or no tidal currents. Ambient levels were quite low during this period. Measurements on March 13th, 2019 were conducted in relatively rough conditions when there were 5-10 meter/second winds and 1-meter seas and no vessel traffic. Measurements conducted on April 13th, 2019 were conducted under relatively calm conditions with 2 to 5 meter per second wind and seas of about 0.3 meters. There was some distant vessel traffic.

Figure 22 shows the 1/3rd octave band spectra for these varying conditions. Overall sound levels were computed over the frequency range of 20 to 20,000 Hz. During calm conditions encountered on March 11th, 2019, overall RMS sound levels were measured at 97 dB. These were quiet conditions and the measured sound level reflects the instrument noise floor. During rough conditions, the overall sound levels were 126 dB, dominated by low frequency sounds below 500 Hz, with highest levels below 50 Hz. During April 13th, 2019, background sound levels were 105 dB.

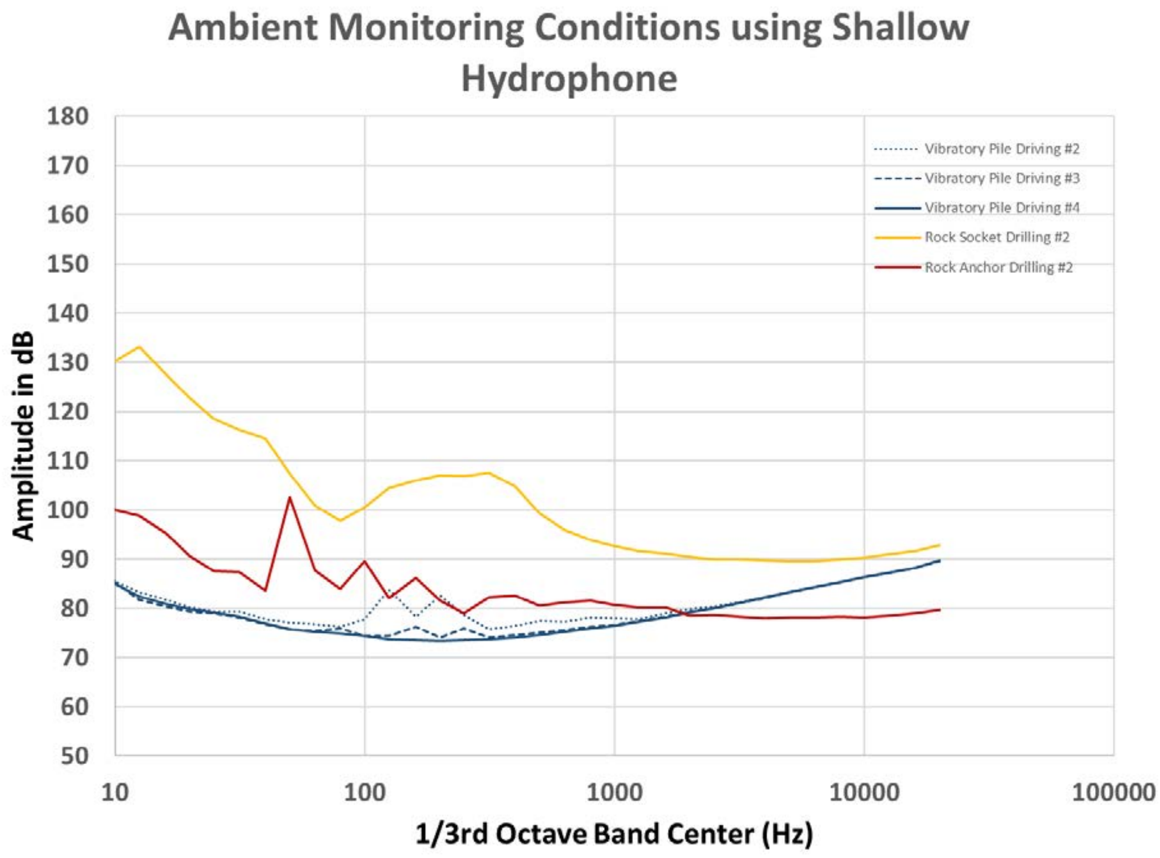

Figure 22. Median 1/3rd octave band sound levels for ambient conditions measured 0.6 to 7 kilometers from WP&RR dock in Taiya Inlet.

CONCLUSIONS

This project involved the installation of 42-inch diameter steel piles to construct two mooring dolphins for large ships at the south end of the WP&RR dock at the northern end of the Taiya Inlet. Each Dolphin consisted of one vertical and three battered piles. The inlet at this location is deep and piles were over 200 feet long. This study measured the sounds generated by vibratory pile driving, impact pile driving, rock socket drilling, and rock anchor drilling sounds.

Vibratory installation of piles were measured for four events that were about 5 minutes in duration each. Near source RMS sound pressure levels, transmission coefficients, and marine mammal WFAs were computed based on these data.

Transmission Loss Coefficient	Computed Vibratory Sound Levels at 10 meters					
	Unweighted Median	LF Cetacean	MF Cetacean	HF Cetacean	Phocid Pinnipeds	Otariid Pinnipeds
17.2 RMS	RMS: 170 dB (sec)	Note: Maximum peak pressure measured = 195 dB at 10m				
	201 dB (Based on 1362 seconds)	168 dB	143 dB	138 dB	188 dB	190 dB
	Distance to 120 dB(unweighted) = **6,900 meters**					

Impact Driving of piles was measured for three events that were about 5 minutes, one minute, and one minute in duration. Near source peak pressures, RMS sound pressure levels (Pulse and Impulse), SELs, transmission coefficients, and marine mammal WFAs were computed based on these data.

Transmission Loss Coefficient	Computed Pile Impact Sound Levels at 10 meters					
	Unweighted Median	**LF Cetacean**	**MF Cetacean**	**HF Cetacean**	**Phocid Pinnipeds**	**Otariid Pinnipeds**
16.3 Peak 16.6 RMSpulse 15.0 SEL	Peak: 205 dB					
	RMSpulse: 190	Note: Impulse RMS= 191 dB				
	SEL: 178 dB (sec)					
	203 dB SELacc (Based on 312 pile strikes)	201 dB	177 dB	173 dB	192 dB	192 dB
	Distance to 160 dB(unweighted) = **590 meters** (computed) and just over 700 meters (measured)					

Pile Rock Socket Drilling was measured for two events that had durations of about 35 minutes on one day and 10 minutes on a separate day. Near source peak pressures, RMS sound pressure levels (median 1 sec and Impulse), SELs, transmission coefficients, and marine mammal WFAs were computed based on these data.

Transmission Loss Coefficient	Computed Rock Socket Sound Levels at 10 meters					
	Unweighted Median	**LF Cetacean**	**MF Cetacean**	**HF Cetacean**	**Phocid Pinnipeds**	**Otariid Pinnipeds**
16.7 peak ~15.9 RMSpulse 16.2 SEL	Peak: 203 dB	Note: Maximum measured peak was 199 dB				
	RMSimpulse: 184	Note: Pulse measurements not conducted but computed from SEL using 0.03sec and measured using RMS impulse detector				
	RMS/SEL: 179 dB (sec)					
	212 dB SEL (Based on 2036 sec)	210 dB	180 dB	175 dB	199 dB	199 dB
	Distance to 120 dB (unweighted) based on cont. RMS = **43 kilometers** (computed) Approximate distance to 160 dB (pulse) based on RMSimpulse = **330 meters**					

Rock Anchor Drill Casing Impact Driving was measured close-in for three separate events of about 5 minutes, four and one-half minutes, and one and one-half minute. Near source peak pressures, RMS sound pressure levels (Pulse and Impulse), SELs, and marine mammal WFAs were computed based on these data. Only close-in measurements were made; therefore, TL coefficients could not be computed. A 15*Log function of the distance from the casing was used to compute the near-source (10 meters) levels.

Transmission Loss Coefficient	Computed Rock Anchor Casing Sound Levels at 10 meters					
	Unweighted Median	**LF Cetacean**	**MF Cetacean**	**HF Cetacean**	**Phocid Pinnipeds**	**Otariid Pinnipeds**
-- peak -- RMSpulse -- SEL	Peak: 182 - 195 dB					
	RMSpulse: 169-178	Note: Impulse RMS= 170-180 dB				
	SEL: 163-171 dBsec					
	195 dB SEL (Based on 681 seconds and med. SEL of 167dB)	195 dB	178 dB	174 dB	191 dB	190 dB
	Distance to 160 dB(unweighted) based on median pulse of 173dB = **160 meters** (computed)					

Rock Anchor Drilling was measured close-in for three separate events of about 20 minutes, 10 minutes, and almost 40 minutes. Near source peak pressures, RMS sound pressure levels (median 1 sec and Impulse), SELs, transmission coefficients, and marine mammal WFAs were computed based on these data.

Transmission Loss Coefficient	**Computed Rock Anchor Drilling Sound Levels at 10 meters**					
	Unweighted Median	**LF Cetacean**	**MF Cetacean**	**HF Cetacean**	**Phocid Pinnipeds**	**Otariid Pinnipeds**
28 RMS	RMS: 157 dB (sec)	Note: Maximum peak pressure measured computed at 170 dB at 36m				
	193 dB (Based on 4265 seconds)	191 dB	173 dB	171 dB	184 dB	184 dB
	Distance to 120 dB(unweighted) = 205 meters (computed)					

Appendix A – Glossary of Technical Terms and Description of Weighting Frequency Adjustment Application

Ambient sound – Normal background sound in the environment that has no distinguishable sources.

Ambient sound level – The background sound pressure level at a given location, normally specified as a reference level to study a new intrusive sound source.

Amplitude – The maximum deviation between the sound pressure and the ambient pressure.

Background level – Similar to ambient sound level with the exception that is a composite of all sound measured during the construction period minus the pile removal.

Continuous sound - A sound whose fluctuating sound pressure level remains above ambient sound during the event period (e.g., vibratory pile driving). In this report, non-impulsive sounds are considered continuous sounds.

Decibel (dB) – A customary scale most commonly used for reporting levels of sound. A difference of 10 dB corresponds to a factor of 10 in sound power. 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 water is 1 microPascal, and for air it is 20 microPascals (the threshold of healthy human auditory sensitivity).

Fast, Slow, and Impulse – Most sound level meters have two conventional time weightings, F = Fast and S = Slow with time constants of 125 milliseconds (ms) and 1,000 ms, respectively. Some also have I = Impulse time weighting, which is a quasi-peak detection characteristic with rapid rise time (35 ms) and a much slower 1.5-second decay.

- F = 125 ms up and down
- S = 1 second up and down
- I = 35 ms while the signal level is increasing or 1,500 ms while the signal level is decreasing.

Frequency – The number of complete pressure fluctuations per second above and below atmospheric pressure, measured in cycles per second (Hertz [Hz]). Normal human hearing is between 20 and 20,000 Hz. Infrasonic sounds are below 20 Hz and ultrasonic sounds are above 20,000 Hz.

Frequency spectrum – The distribution of frequencies that comprise a sound.

Hertz (Hz) – The units of frequency where 1 Hz equals 1 cycle per second.

Impulsive Sound – Transient sounds that are brief (less than 1 second) that are characterized by high peak sound pressure with rapid rise time and rapid decay. These sounds can occur in prepetition (e.g., pile driving) or a single event (e.g., explosion). There is no definition of the repetitive rate that defines a sound as impulsive or continuous.

Kilohertz (kHz) – 1,000 Hz

L_{eq} – *Equivalent Average Sound Pressure Level (or Energy-Averaged Sound Level).* The decibel level of a constant noise source that would have the same total acoustical energy over the same time interval as the actual time-varying noise condition being measured or estimated. L_{eq} values must be associated with an explicit or implicit averaging time in order to have practical meaning. The use of A-weighted, C-weighted, or Z-weighted (flat) decibel units sometimes is indicated by LA_{eq}, LC_{eq}, or LZ_{eq}, respectively

LZ_{eq} – Z-weighted, L_{eq}, sound pressure level.

LZ_{max} – Maximum Sound Pressure level during a measurement period or a noise event.

LZ_{peak} – Z-weighted peak sound pressure level.

microPascal (μPa) – The Pascal (symbol Pa) is the SI unit of pressure. It is equivalent to one Newton per square meter. There are 1,000,000 microPascals in one Pascal.

Peak sound pressure level (L_{PEAK}) – The largest absolute value of the instantaneous sound pressure. This pressure is expressed in decibels (referenced to a pressure of 1 μPa for water and 20 μPa for air) or in units of pressure, such as μPa or Pounds per Square Inch.

Root mean square (RMS) sound pressure level – Decibel measure of the square root of mean square (RMS) pressure. For individual pulses, the average of the squared pressures over the time that comprise that portion of the waveform containing 90 percent of the sound energy of the impulse. For continuous sounds, a time constant is used. To define continuous sources in this SSV, a time constant of one second was used over the duration of activities.

SLM – Sound level meter. In this SSV, the Lason Davis model 831 sound level meter was used.

Sound – Small disturbances in a fluid from ambient conditions through which energy is transferred away from a source by progressive fluctuations of pressure (or sound waves).

Sound exposure – The integral over all time of the square of the sound pressure of a transient waveform.

Sound exposure level (SEL) – The time integral of frequency-weighted squared instantaneous sound pressures. Proportionally equivalent to the time integral of the pressure squared. Sound energy associated with an acoustical event is characterized by the SEL. SEL is the constant sound level in one second, which has the same amount of acoustic energy as the original time-varying sound (i.e., the total energy of an event). SEL is calculated by summing the cumulative pressure squared over the time of the event ($1\mu Pa^2$-sec).

Sound pressure level (SPL) – An expression of the sound pressure using the decibel (dB) scale and the standard reference pressures of 1 μPa for water and 20 μPa for air when addressing human concerns. Sound pressure is the sound force per unit area, usually expressed in microPascals (or microNewtons 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 SPL is expressed in dB as one or 20 times the logarithm to the base 10 of the ratio between the pressure exerted by the sound to a reference sound pressure. SPL is the quantity directly measured by a sound level meter.

Weighting Factor Adjustment (WFA) – Adjustments to sound levels based on marine mammal auditory weighting functions that focus on a single frequency. These adjustments are applied to the following marine mammal hearing groups: Low-frequency (LF) cetaceans, Mid-frequency (MF) cetaceans, High-frequency (HF) cetaceans, Phocid pinnipeds (underwater), and Otariid pinnipeds (underwater).

Z-weighted – Z-weighting is a flat frequency response of 10 Hz to 20 kHz ±1.5 dB. This response replaces the older "Linear" or "Unweighted" responses as these did not define the frequency range over which a sound level meter would be linear.

A-Weighted - 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.

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TECHNICAL MEMO

Calculation of One-Third Octave Band Weighting Factors for Marine Mammals

In NOAA Technical Memorandum NMFS-OPR-55 (July 2016, updated 2018), weighting functions are defined for five different species of marine mammals. These weighting functions are defined the following equation and the appropriate parameters to be used for the different species:

$$W(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a\,[1+(f/f_2)^2]^b}\right\}$$

Hearing Group	*a*	*b*	f_1 (kHz)	f_2 (kHz)	*C* (dB)	*K* (dB)
Low-frequency (LF) cetaceans	1.0	2	0.2	19	0.13	179
Mid-frequency (MF) cetaceans	1.6	2	8.8	110	1.20	177
High-frequency (HF) cetaceans	1.8	2	12	140	1.36	152
Phocid pinnipeds (PW) (underwater)	1.0	2	1.9	30	0.75	180
Otariid pinnipeds (OW) (underwater)	2.0	2	0.94	25	0.64	198

The weighting factors determined by this equation apply to individual frequencies such as to be used with narrow-band data or power spectral densities (PSD). Much of the underwater construction data is actually captured and reported in one-third octave bands. In order to apply the weighting factors to one-third octave band data, the simplest method is just add the weighting calculated by the above equation at the one-third octave band center frequency to the measured one-third octave band data. Slightly more rigorously, the one-third octave band average weighting can be calculated by averaging several frequencies within the one-third octave band to develop a band-averaged frequency weighting. If the data is captured in narrow-band or as a PSD, the weighting calculated by the equation can be used to calculate the weighting for each frequency, apply that to the narrow-band data, and then sum this into one-third octave band levels.

To evaluate these approaches, data from an actual impact pile driving event was used. For this example, the Otariid Pinnipeds weighting is used. These data were analyzed in narrow-band and true one-third octave band meeting ANSI specifications. The narrow-band data was produced in 3.13 Hz wide bands. To evaluate using only the one-third octave band center frequency versus the average of several frequencies within a band, the weighting for each of the frequencies considered (typically five) were average together. This process is presented in the accompanying Excel spreadsheet under Tab "Guidance Sheet O Thd OB". Column A shows the one-third octave band center frequency and column C shows the weighting value corresponding to the frequency. Column B also shows the other frequencies within a specific one-third octave band that were in the average and column C shows the weighting value at each of these frequencies. The band average weighting and center frequency only weighting are shown in columns O and P, respectively. The band average weighting is just the arithmetic mean of values within a band. The difference between these is shown in column Q. These differences are quite small, typically 0.0 dB with some at ±0.1 and one maximum of 0.2 dB. Generally, the differences become less and more consistently 0.0 dB at higher frequency. This is somewhat expected as the "steepness" of the weighting is greater in the low frequency as shown in Figure 1. Since there is more variation in the weighting across a lower frequency one-third octave band, the average differs slightly from the single center frequency value. However, using the center frequency only to represent the one-third octave band appears to be quite adequate.

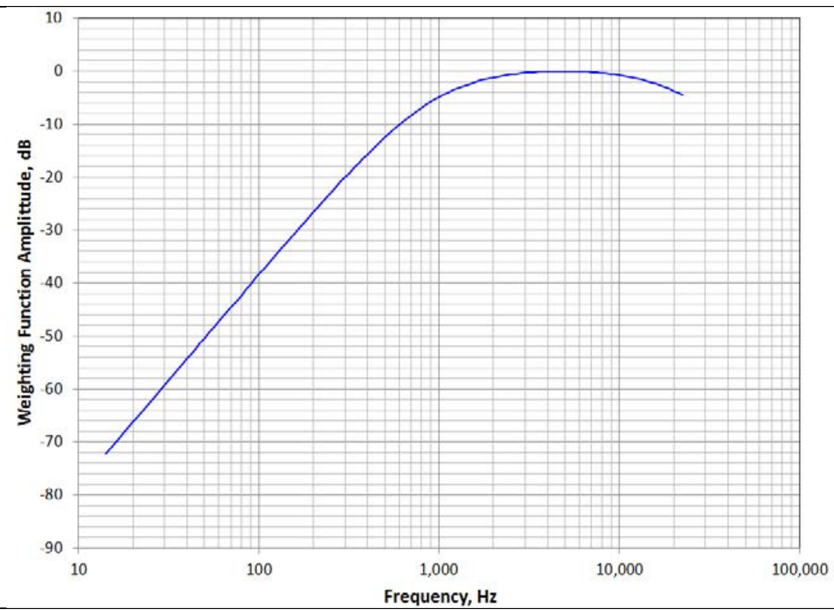

Figure 1: Otariid Pinnipeds weighting curve up to 12,500 Hz

Determining one-third octave band by first weighting narrow-band or PSD and then summing the results into one-third octave band presents several difficulties. For comparison, this was done again using the impact pile driving data. This is documented in Tab "Calculations" of the accompanying file. The band frequency and measured unweighted levels are presented in columns A and B. The weighting for each frequency is calculated in column D and applied in column E. The overall unweighted and O weighted levels are at the top of columns C and F. In Columns J through L, the result of summing the weighted narrow-band into one-third octave bands is shown along with the overall level summed at the top of Column K. The actual levels and frequencies used in summing the individual one-third octave band levels are color-coded in column A. The overall levels between the sum of the narrow-band and one-third octave band levels are virtually identical. In columns M through R, the calculations are done using one-third octave band levels from the direct one-third octave band data and with the band averaged weighting applied. The final measured and weighted one-third octave band levels are shown in column R, It should be noted that the number of narrow-band point going into an individual one-third octave band decreases significantly with lower frequency; for the 20, 25, and 31.5 bands, only two levels are summed per band. For the 12.5 Hz band, only one narrow-band level is included. Although using PSD could help to a degree, at these lower frequencies, the one-third octave band limits are expressed in tenths of Hz so that a PSD equivalent is not sufficient. In column S the difference between the one-third octave band levels calculated from measured one-third octave band levels and those synthesized from narrow-band data are shown. At the lowest frequency (12.5 Hz), there is a large (16.9 dB) difference between the actual and synthesized results. Above 630 Hz, the differences become insignificant after fluctuating for the band up that point. For computing overall levels, there is very little difference in the method used. As shown by the levels at the top of columns F, K, and R, levels are all 165.4 dB.

In summary, it was found there is little difference in using the weighting at the one-third octave band center frequency or using an average over the band. Also, synthesizing one-third octave band levels for narrow-band or PSD data is not accurate at lower frequencies and should be avoided entirely. However, the overall levels using any of these methods are equivalent.

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Weighting Function Parameters	Otariidae
a	2
b	2
f_1	940
f_2	25000
C	0.64

$$W(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a\,[1+(f/f_2)^2]^b}\right\}$$

1/3 OB Center Freq	Freq Narrow Band Freq	Result	Calculation for Otariid Pinnipeds (OW) f/f1	f/f2	(f/f1)^2a	(f/f1)^2	(1+(f/f1)^2)a	(1+(f/f2)^2)^b						Average Weighting	Center Freq Weighting	Difference
	8.9	-80.29276207	0.0095	0.0003564	8.07E-09	8.98E-05	1.00017966	1.00000025	8.07E-09		-80.2928					
	9.4	-79.36086977	0.01	0.000376	1E-08	0.0001	1.00020001	1.00000028	1E-08		-79.3609					
10	10	-78.28609849	0.0106	0.0004	1.28E-08	0.000113	1.00022636	1.00000032	1.28E-08		-78.2861		10	-78.3	-78.3	0.0
	10.6	-77.27398554	0.0113	0.000424	1.62E-08	0.000127	1.000254339	1.00000036	1.62E-08		-77.274					
	11.1	-76.41680099	0.0118	0.0004454	1.97E-08	0.00014	1.000280725	1.0000004	1.97E-08		-76.4168					
	11.8	-75.41120442	0.0126	0.000472	2.48E-08	0.000158	1.00031519	1.00000045	2.48E-08		-75.4112					
12.5	12.5	-74.41025161	0.0133	0.0005	3.13E-08	0.000177	1.000353698	1.0000005	3.13E-08		-74.4103		12.5	-74.4	-74.4	0.0
	13.3	-73.33278964	0.0141	0.000532	4.01E-08	0.0002	1.000400425	1.00000057	4.01E-08		-73.3328					
	14.1	-72.31830651	0.015	0.000564	5.06E-08	0.000225	1.000450051	1.00000064	5.06E-08		-72.3183					
	15	-71.2436784	0.016	0.0006	6.48E-08	0.000255	1.000509345	1.00000072	6.48E-08		-71.2437					
16	16	-70.12283454	0.017	0.00064	8.39E-08	0.00029	1.000579532	1.00000082	8.39E-08		-70.1228		16.0	-70.2	-70.1	-0.1
	17	-69.07000174	0.0181	0.00068	1.07E-07	0.000327	1.000654249	1.00000092	1.07E-07		-69.07					
	17.8	-68.27143247	0.0189	0.000712	1.29E-07	0.000359	1.000717286	1.00000101	1.28E-07		-68.2714					

Figure A. Guidance Sheet O Thd OB

Measured Data Data for Strike 2025 Freq	Narrowband Meas Level dB	Measured Unweighted 10^(L/10) Overall 174.19	O Weightiing Values	O Weightiing Applied	10^(L/10) Overall O Wtd 165.35	Center Freq	1/3rd Oct Band Limits Upper	Lower	Center Freq	1/3 Oct Band from O Weighted Narrow Band Overall O Wtd 165.36		Center Freq	Measured Data Meas Level 1/3rd Oct Band dB	Unweighted Overall 174.28	O Weightiing Values	O Weightiing Applied	1/3 Oct Band from O Weighted 1/3 Oct Band Overall O Wtd 165.40	Difference
0		1				1.25			1.25			1.25						
3.13	91.70	1.48E+09	-98.47	-6.77	2.10E-01	1.6			1.6			1.6						
6.26	91.74	1.49E+09	-86.43	5.30	3.39E+00	2			2			2						
9.38	92.08	1.61E+09	-79.39	12.69	1.86E+01	2.5			2.5			2.5						
12.51	104.29	2.69E+10	-74.39	29.90	9.76E+02	3.15			3.15			3.15						
15.64	121.13	1.30E+12	-70.52	50.61	1.15E+05	4			4			4						
18.77	130.79	1.20E+13	-67.35	63.44	2.21E+06	5			5			5						
21.90	134.71	2.96E+13	-64.67	70.04	1.01E+07	6.3			6.3			6.3						
25.02	136.73	4.71E+13	-62.36	74.37	2.74E+07	8			8			8						
28.15	140.17	1.04E+14	-60.31	79.86	9.68E+07	10	11.22	8.91	10			10	104.29	2.6853E+10	-78.3	26.0	3.95E+02	
31.28	138.57	7.19E+13	-58.48	80.08	1.02E+08	12.5	14.10	11.22	12.5	9.76E+02	29.9	12.5	121.22	1.3242E+12	-74.4	46.8	4.83E+04	16.9
34.41	134.14	2.59E+13	-56.83	77.31	5.38E+07	16	17.80	14.10	16	115155.58	50.6	16	131.24	1.33E+13	-70.2	61.0	1.27E+06	10.4
37.54	141.72	1.49E+14	-55.32	86.40	4.37E+08	20	22.40	17.80	20	1.23E+07	70.9	20	136.19	4.1601E+13	-66.3	69.9	9.83E+06	-1.0
40.66	145.60	3.63E+14	-53.93	91.67	1.47E+09	25	28.20	22.40	25	1.24E+08	80.9	25	141.79	1.5108E+14	-62.3	79.5	8.93E+07	-1.4
43.79	144.46	2.79E+14	-52.65	91.81	1.52E+09	31.5	35.50	28.20	31.5	1.56E+08	81.9	31.5	143.92	2.464E+14	-58.2	85.7	3.70E+08	3.8
46.92	142.65	1.84E+14	-51.45	91.20	1.32E+09	40	44.70	35.50	40	3.42E+09	95.3	40	149.89	9.7479E+14	-54.3	95.6	3.66E+09	0.3
50.05	138.83	7.63E+13	-50.33	88.49	7.07E+08	50	56.20	44.70	50	3.66E+09	95.6	50	148.81	7.6014E+14	-50.3	98.5	7.02E+09	2.8
53.18	141.43	1.39E+14	-49.28	92.14	1.64E+09	63	70.80	56.20	63	1.54E+10	101.9	63	147.80	6.0243E+14	-46.4	101.4	1.38E+10	-0.5
56.30	145.58	3.61E+14	-48.29	97.28	5.35E+09	80	89.10	70.80	80	4.59E+10	106.6	80	153.70	2.3425E+15	-42.3	111.4	1.38E+11	4.8
59.43	144.66	2.92E+14	-47.36	97.30	5.37E+09	100	112.00	89.10	100	6.47E+11	118.1	100	158.90	7.762E+15	-38.4	120.5	1.13E+12	2.4
62.56	140.34	1.08E+14	-46.47	93.87	2.44E+09	125	141.00	112.00	125	8.52E+12	129.3	125	163.65	2.3172E+16	-34.4	129.2	8.41E+12	-0.1
65.69	123.40	2.19E+12	-45.63	77.77	5.98E+07	160	178.00	141.00	160	1.63E+13	132.1	160	164.06	2.5488E+16	-30.5	133.6	2.29E+13	1.5
68.82	138.13	6.50E+13	-44.82	93.31	2.14E+09	200	224.00	178.18	200	4.46E+13	136.5	200	163.32	2.1477E+16	-26.6	136.7	4.66E+13	0.2
71.95	141.29	1.34E+14	-44.06	97.23	5.29E+09	250	282.00	224.00	250	7.05E+13	138.5	250	161.14	1.2989E+16	-22.9	138.3	6.73E+13	-0.2
75.07	142.55	1.80E+14	-43.32	99.23	8.38E+09	315	355.00	282.00	315	5.81E+14	147.6	315	166.11	4.0811E+16	-19.2	146.9	4.86E+14	-0.8
78.20	142.12	1.63E+14	-42.62	99.50	8.91E+09	400	447.00	355.00	400	5.98E+14	147.8	400	163.24	2.1062E+16	-15.7	147.5	5.68E+14	-0.2

Figure B. Calculations

Appendix B – Pile Log Sheets

Railroad Dock Mooring Dolphins 4/5
Pile Installation Log

Date:	3/11/2019	Pile Location:	MD4
Time:	7:00PM	Pile Number:	Vertical
Conditions:	Overcast	Inspector:	Pat Joens

Pile Data Per Plans			As-Built Pile Data		
Pile Size:	42"		Pile Size:	42"	
Mudline Elevation:	-112	Feet	Starting Elevation:	-115	Feet
Push Elevation:	-122	Feet	Push Elevation:	-125	Feet
Bedrock Elevation:	-190	Feet	Bedrock Elevation:	-165	Feet
Bottom of Pile Elevation:	-201	Feet	Bottom of Pile Elevation:	-172	Feet
Socket Length (Vertical):	10	Feet	Socket Length:	7	Feet
Batter :	N/A	rise/run	Batter:	N/A	rise/run

*On batter, lenghts are measured along the pile; not vertically.

Pile As-built Details

Vibe Pile			**Stroke**	**Inch**	**Cuttings**	**Blow #**
Date/ Time Initaiate Driving Through Soil:	3/6/2019	10:00				
Start/Actual Mudline Elevation:	-115	Feet				
End/Actual Bedrock Elevation:	-163	Feet				
Date/ Time Stop Driving Through Soil:	3/8/2019	17:00				
Impact Pile						
Date/ Time Initaite Driving Through Rock:	3/11/2019	11:00				
Impact Start Elevation	-163	Feet				
Impact Refusal	-165	Feet				
Date/ Time Initaite Driving Through Rock:	3/11/2019	11:05				
			~10ft	1	HM	8
Drill Pile			~10ft	2	HM	8
Date/ Time Initaite Drilling Through Rock:	3/11/2019	14:00	~10ft	3	HM	7
Final Elevation of Pile Tip:	-172	Feet	~10ft	4	HM	10
*Penetration of Pile into Rock:	7	Feet	~10ft	5	HM	9
Date/ Time Initaite Drilling Through Rock:	3/11/2019	18:00	~10ft	6	HM	10

Additional Notes & Comments

Blow count is for last 6 inches of impact @ MD4-Vert
Template @ +20ft elevation
Cut Off: +205 ft

Drill from -165ft to -172ft. Hard competent rock

SD; Sediment, FN: Fines, CB: Cobbles
HM: Hammering, ES Easy Drilling

Inspector Signature: Pat Joens

Date: 3/12/2019

Railroad Dock Mooring Dolphins 4/5
Pile Installation Log

Date:	3/29/2019	Pile Location:	MD4-NE
Time:	11:00AM	Pile Number:	Northeast 3:1 Batter
Conditions:	Overcast	Inspector:	Shem Sooter

Pile Data Per Plans			As-Built Pile Data		
Pile Size:	42"		Pile Size:	42"	
Mudline Elevation:	-85	Feet	Starting Elevation:	-79	Feet
Push Elevation:	N/A	Feet	Push Elevation:	-104	Feet
Bedrock Elevation:	-130	Feet	Bedrock Elevation:	-112	Feet
Bottom of Pile Elevation:	-140	Feet	Bottom of Pile Elevation:	-130	Feet
Socket Length (Vertical):	10	Feet	Socket Length:	18	Feet
Batter :	N/A	rise/run	Batter:	N/A	rise/run

*On batter, lenghts are measured along the pile; not vertically.

Pile As-built Details

Vibe Pile			Stroke	Inch	Cuttings	Blow #
Date/ Time Initaiate Driving Through Soil:	3/31/2019	9:00				
Start/Actual Mudline Elevation:	-79	Feet				
End/Actual Bedrock Elevation:	-112	Feet				
Date/ Time Stop Driving Through Soil:	3/31/2019	10:15				

Impact Pile		
Date/ Time Initaite Driving Through Rock:	N/A	
Impact Start Elevation	N/A	Feet
Impact Refusal	N/A	Feet
Date/ Time Initaite Driving Through Rock:	N/A	

Drill Pile		
Date/ Time Initaite Drilling Through Rock:	4/1/2019	15:45
Final Elevation of Pile Tip:	-130	Feet
*Penetration of Pile into Rock:	18	Feet
Date/ Time Initaite Drilling Through Rock:	4/1/2019	17:00

Additional Notes & Comments

Template @ +20ft elevation

Mudline: -79 at catch point, tide (+) 11' and sounding -103

Drill from -112ft to -130ft. bedrock

SD; Sediment, FN: Fines, CB: Cobbles
HM: Hammering, ES Easy Drilling

Inspector Signature: Shem Sooter

Date: 4/3/2019

Railroad Dock Mooring Dolphins 4/5
Pile Installation Log

Date:	4/2/2019	Pile Location:	MD4-E
Time:	8:50AM	Pile Number:	East 3:1 Batter
Conditions:	Sunny	Inspector:	Shem Sooter

Pile Data Per Plans			As-Built Pile Data		
Pile Size:	42"		Pile Size:	42"	
Mudline Elevation:	-83	Feet	Starting Elevation:	-83.5	Feet
Push Elevation:	N/A	Feet	Push Elevation:	-100	Feet
Bedrock Elevation:	-132	Feet	Bedrock Elevation:	-113.5	Feet
Bottom of Pile Elevation:	-142	Feet	Bottom of Pile Elevation:	-128.5	Feet
Socket Length (Vertical):	10	Feet	Socket Length:	15	Feet
Batter :	N/A	rise/run	Batter:	N/A	rise/run

*On batter, lenghts are measured along the pile; not vertically.

Pile As-built Details

Vibe Pile		
Date/ Time Initaiate Driving Through Soil:	4/2/2019	14:00
Start/Actual Mudline Elevation:	-83.5	Feet
End/Actual Bedrock Elevation:	-113.5	Feet
Date/ Time Stop Driving Through Soil:	4/2/2019	15:00

Impact Pile		
Date/ Time Initaite Driving Through Rock:	N/A	
Impact Start Elevation	N/A	Feet
Impact Refusal	N/A	Feet
Date/ Time Initaite Driving Through Rock:	N/A	

Drill Pile		
Date/ Time Initaite Drilling Through Rock:	4/2/2019	16:00
Final Elevation of Pile Tip:	-128.5	Feet
*Penetration of Pile into Rock:	15	Feet
Date/ Time Initaite Drilling Through Rock:	4/2/2019	17:00

Stroke	Inch	Cuttings	Blow #

SD; Sediment, FN: Fines, CB: Cobbles
HM: Hammering, ES Easy Drilling

Additional Notes & Comments

Template @ +20ft elevation
Mudline: -83.5 at catch point, tide (+) 6.50' and sounding -90'

Drill from -113.5 to -128.5 Hard competent rock

Inspector Signature: Shem Sooter

Date: 4/3/2019

Railroad Dock Mooring Dolphins 4/5
Pile Installation Log

Date:	3/28/2019	Pile Location:	MD4-SE
Time:	11:00AM	Pile Number:	Southeast 3:1 Batter
Conditions:	Overcast	Inspector:	Shem Sooter

Pile Data Per Plans			As-Built Pile Data		
Pile Size:	42"		Pile Size:	42"	
Mudline Elevation:	-95	Feet	Starting Elevation:	-105	Feet
Push Elevation:	N/A	Feet	Push Elevation:	-115	Feet
Bedrock Elevation:	-165	Feet	Bedrock Elevation:	-160	Feet
Bottom of Pile Elevation:	-175	Feet	Bottom of Pile Elevation:	-170.5	Feet
Socket Length (Vertical):	10	Feet	Socket Length:	10.5	Feet
Batter :	N/A	rise/run	Batter:	N/A	rise/run

*On batter, lenghts are measured along the pile; not vertically.

Pile As-built Details

Vibe Pile			Stroke	Inch	Cuttings	Blow #
Date/ Time Initaiate Driving Through Soil:	3/20/2019	14:00				
Start/Actual Mudline Elevation:	-105	Feet				
End/Actual Bedrock Elevation:	-160	Feet				
Date/ Time Stop Driving Through Soil:	3/20/2019	15:05				

Impact Pile		
Date/ Time Initaite Driving Through Rock:	N/A	
Impact Start Elevation	N/A	Feet
Impact Refusal	N/A	Feet
Date/ Time Initaite Driving Through Rock:	N/A	

Drill Pile		
Date/ Time Initaite Drilling Through Rock:	3/27/2019	16:15
Final Elevation of Pile Tip:	-160	Feet
*Penetration of Pile into Rock:	-170.5	Feet
Date/ Time Initaite Drilling Through Rock:	3/27/2019	19:50

Additional Notes & Comments

Template @ +20ft elevation

Drill from -160ft to -170.5ft. Hard competent rock

SD; Sediment, FN: Fines, CB: Cobbles
HM: Hammering, ES Easy Drilling

Inspector Signature: Shem Sooter

Date: 3/27/2019

Railroad Dock Mooring Dolphins 4/5
Pile Installation Log

Date:	3/15/2019	Pile Location:	MD5
Time:	7:00AM	Pile Number:	Vertical
Conditions:	Overcast	Inspector:	Pat Joens

Pile Data Per Plans			As-Built Pile Data		
Pile Size:	42"		Pile Size:	42"	
Mudline Elevation:	-118	Feet	Starting Elevation:	-121	Feet
Bedrock Elevation:	-240	Feet	Bedrock Elevation:	-175	Feet
Bottom of Pile Elevation:	-250	Feet	Bottom of Pile Elevation:	-185	Feet
Socket Length (Vertical):	10	Feet	Socket Length:	10	Feet
Batter :	N/A	rise/run	Batter:	N/A	rise/run

*On batter, lenghts are measured along the pile; not vertically.

Pile As-built Details

Vibe Pile		
Date/ Time Initaiate Driving Through Soil:	3/6/2019	10:00
Start/Actual Mudline Elevation:	-121	Feet
End/Actual Bedrock Elevation:	-172	Feet
Date/ Time Stop Driving Through Soil:	3/8/2019	17:00

Impact Pile		
Date/ Time Initaite Driving Through Rock:	3/11/2019	11:00
Impact Start Elevation	-172	Feet
Impact Refusal	-175	Feet
Date/ Time Initaite Driving Through Rock:	3/11/2019	11:05

Drill Pile		
Date/ Time Initaite Drilling Through Rock:	3/11/2019	14:00
Final Elevation of Pile Tip:	-185	Feet
*Penetration of Pile into Rock:	10	Feet
Date/ Time Initaite Drilling Through Rock:	3/11/2019	18:00

Time	Inch	Cuttings	Blow #
~10ft	1	HM	11
~10ft	2	HM	12
~10ft	3	HM	11
~10ft	4	HM	10
~10ft	5	HM	12
~10ft	6	HM	12

SD; Sediment, FN: Fines, CB: Cobbles
HM: Hammering, ES Easy Drilling

Additional Notes & Comments

Blow count is for last 6 inches of impact @ MD5-Vert
Template @ +20ft elevation
Cut Off: +215 ft

Drill from -175ft to -185ft. Hard competent rock

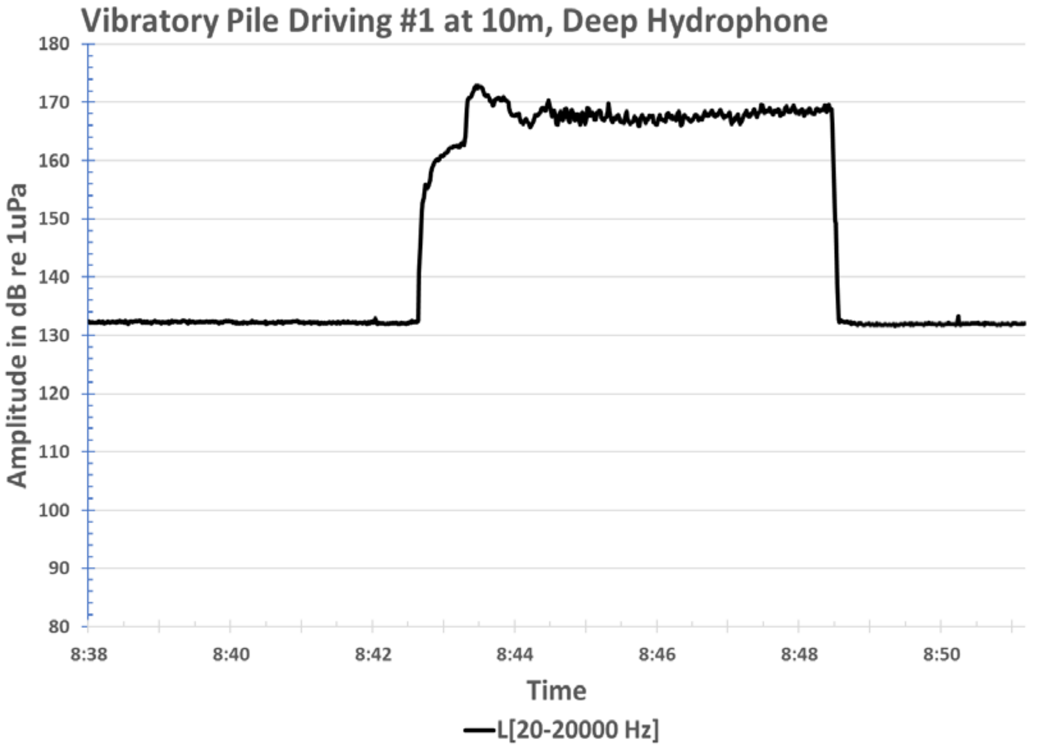
Inspector Signature: Pat Joens

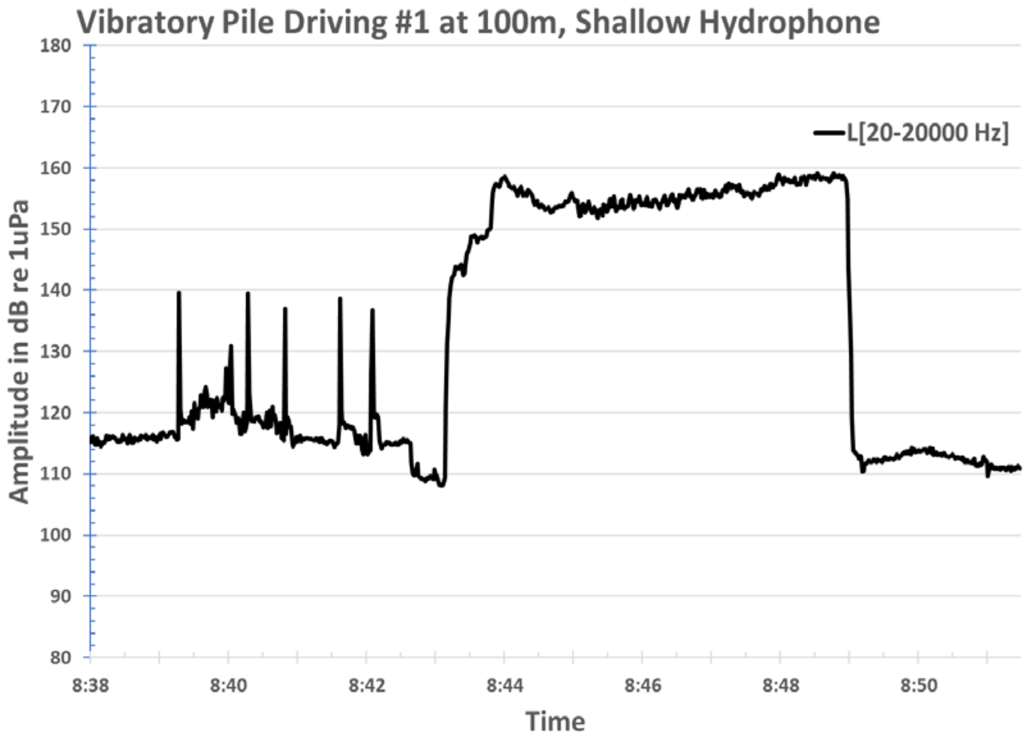
Date: 3/15/2019

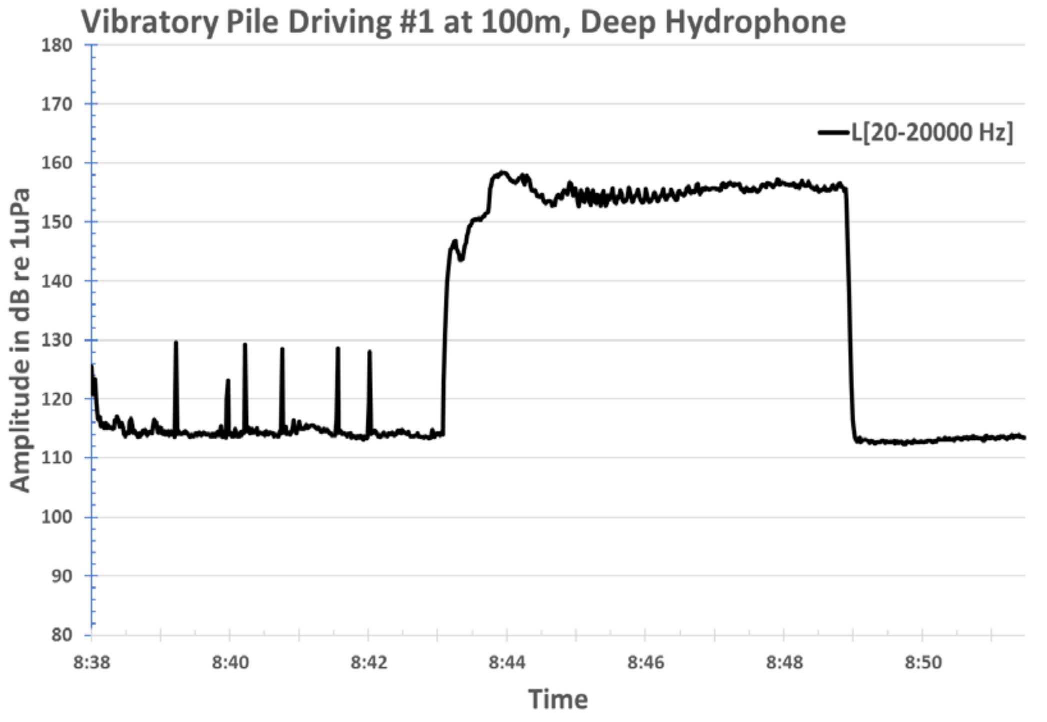
Appendix C – Time History of Measured Sound Events

Vibratory Pile Driving #1
at 10m, Shallow
Hydrophone

N/A

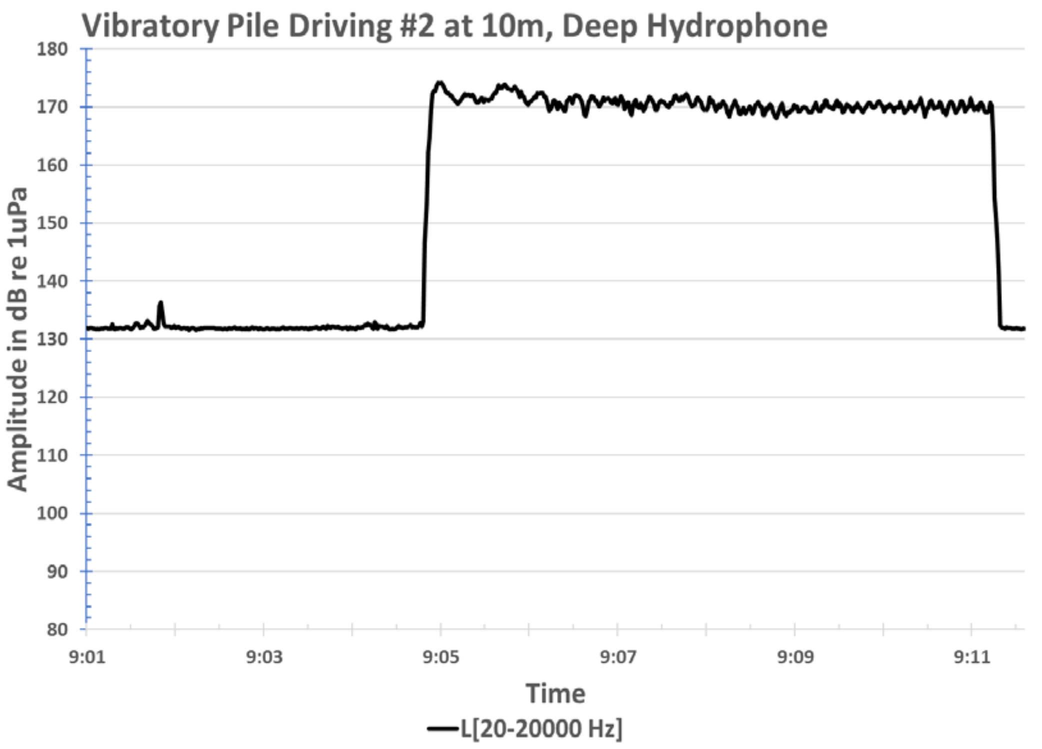


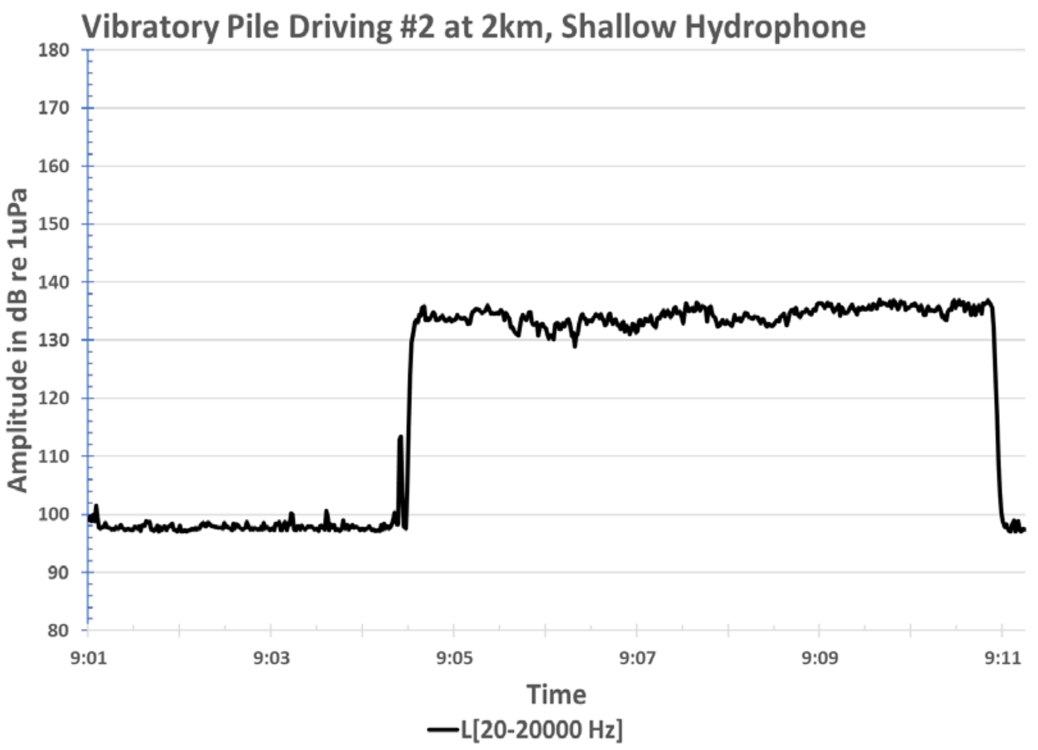


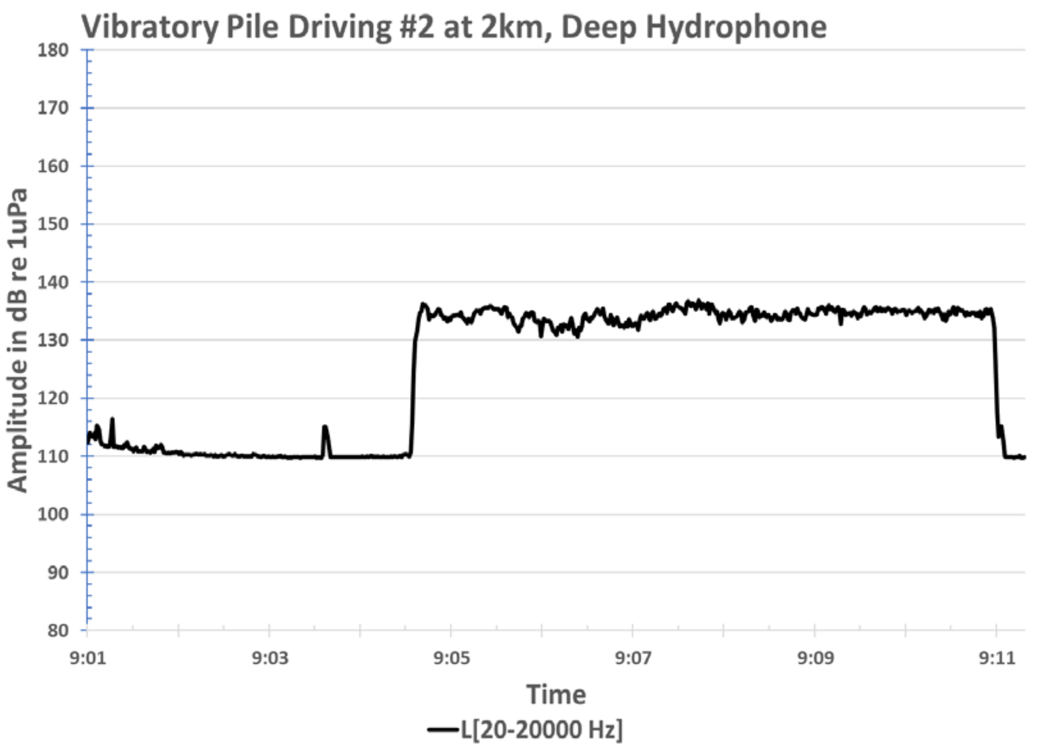


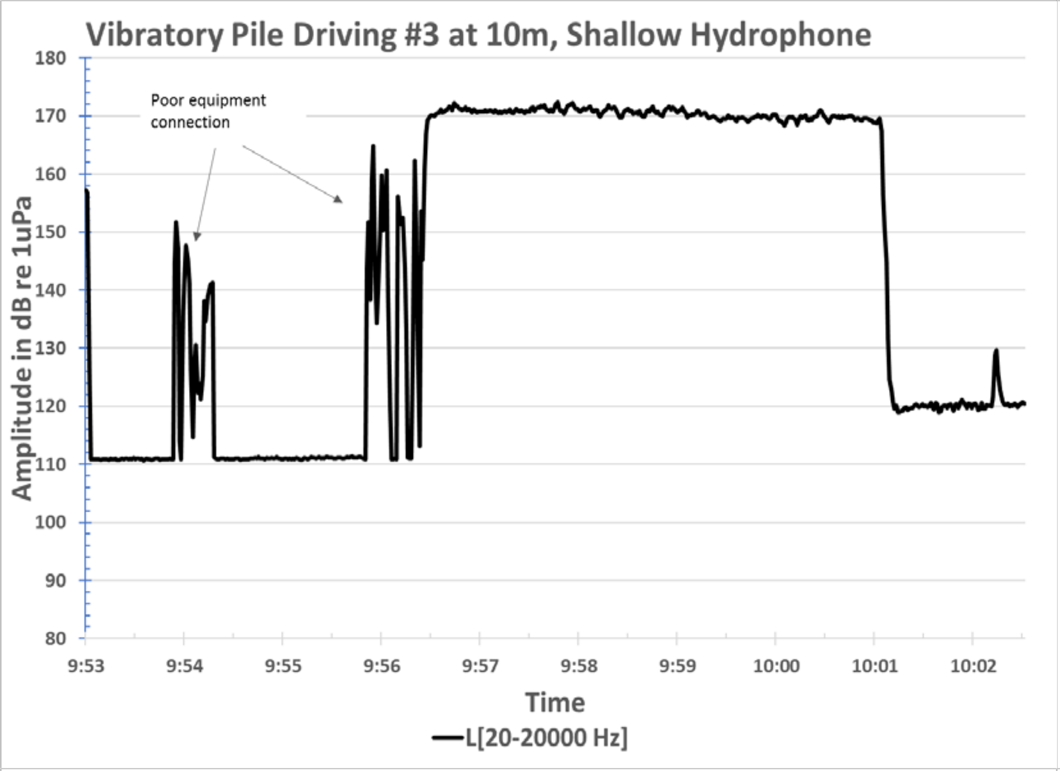
Vibratory Pile Driving #2 at 10m, Shallow Hydrophone

N/A

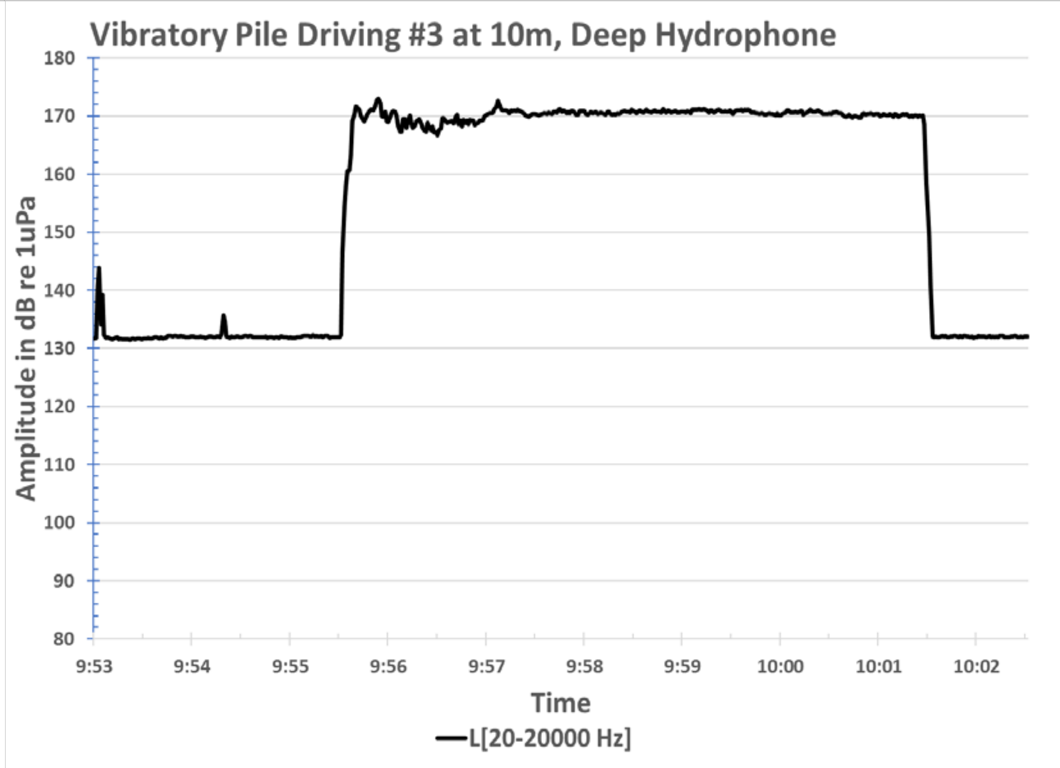




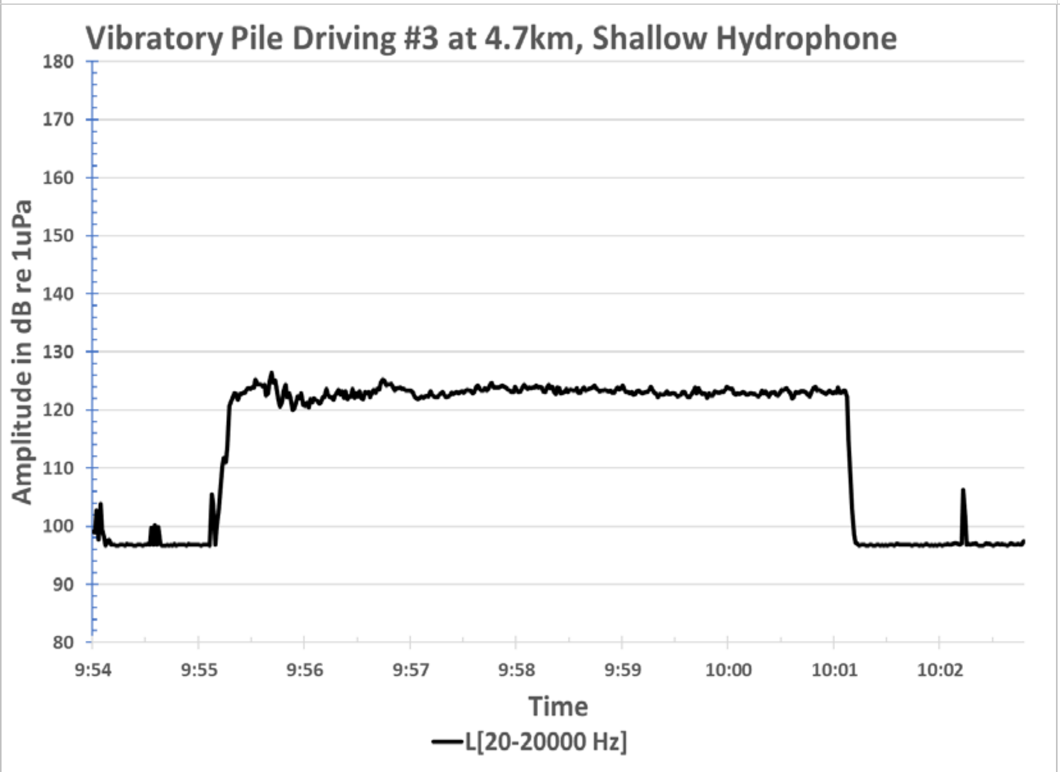




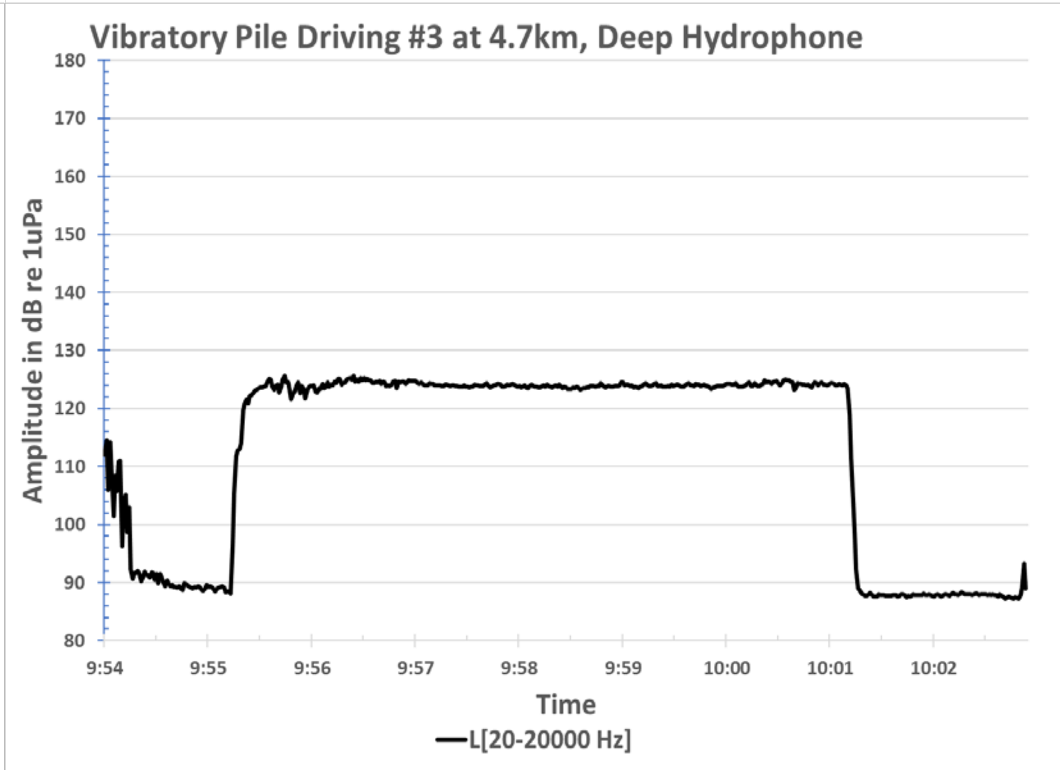
Vibratory Pile Driving #3 at 10m, Shallow Hydrophone
Poor equipment connection
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
9:53
9:54
9:55
9:56
9:57
9:58
9:59
10:00
10:01
10:02
Time
L[20-20000 Hz]



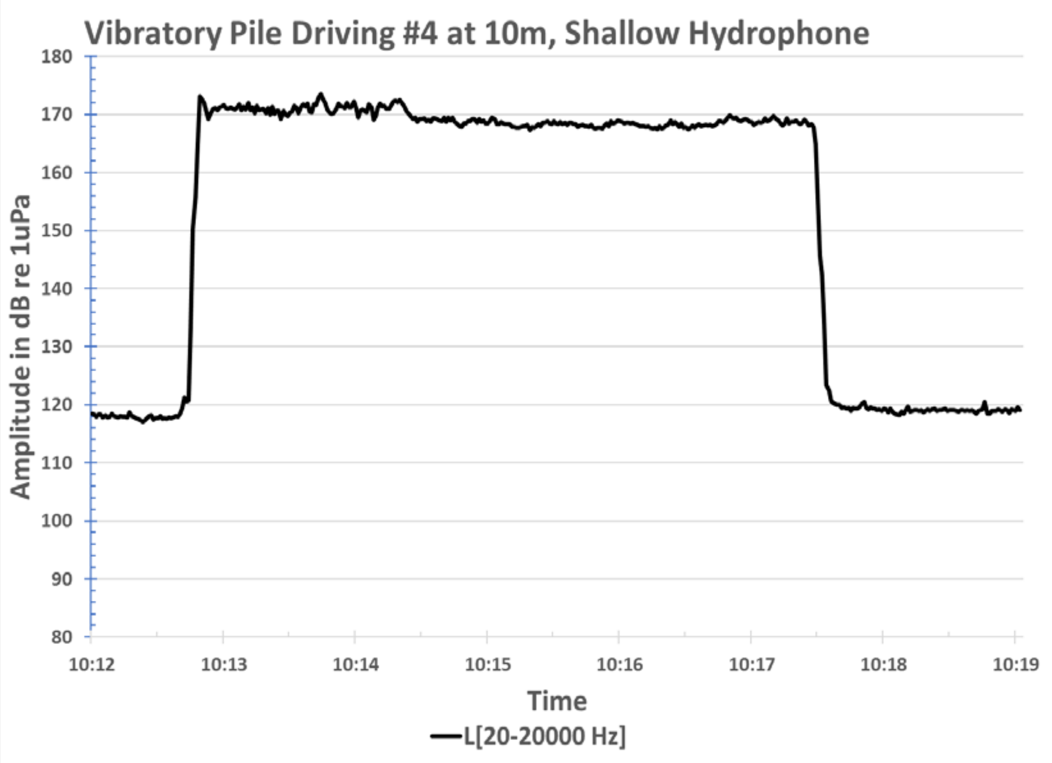
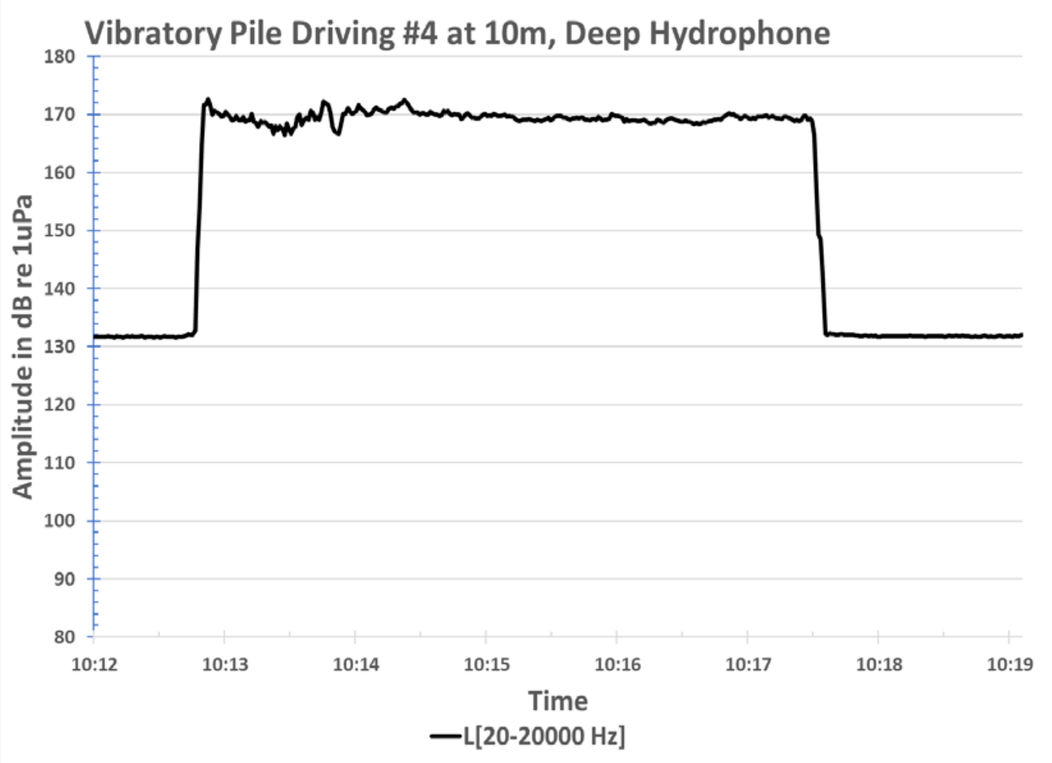
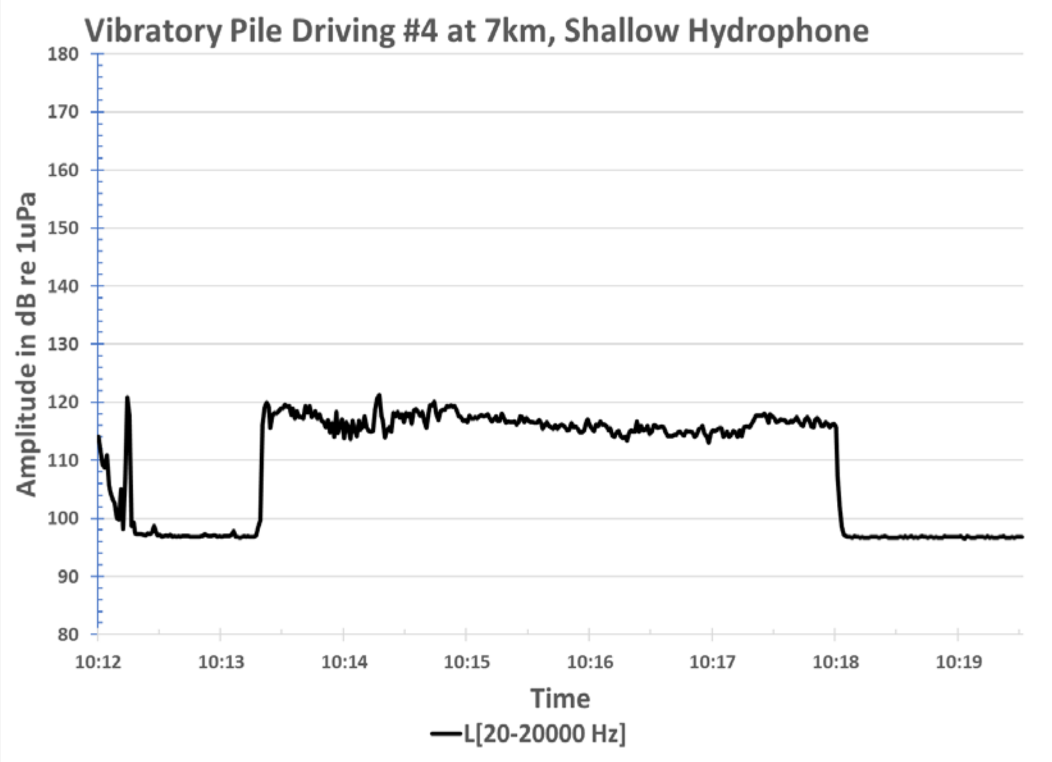
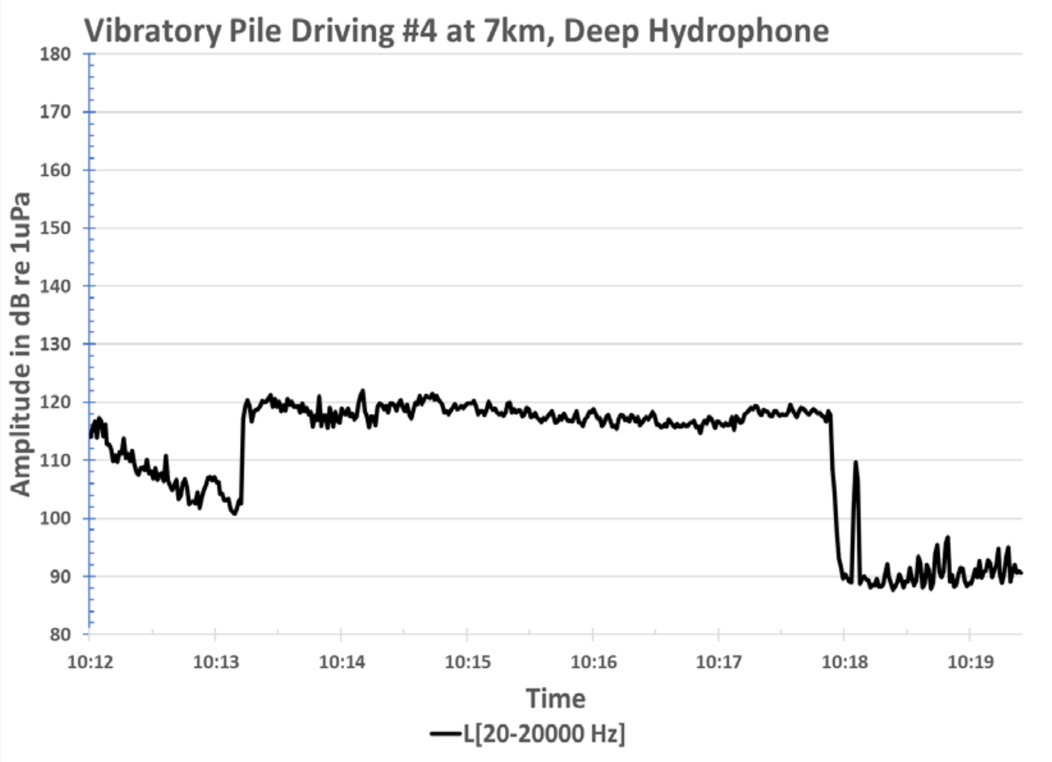
Vibratory Pile Driving #3 at 10m, Deep Hydrophone
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
9:53
9:54
9:55
9:56
9:57
9:58
9:59
10:00
10:01
10:02
Time
L[20-20000 Hz]

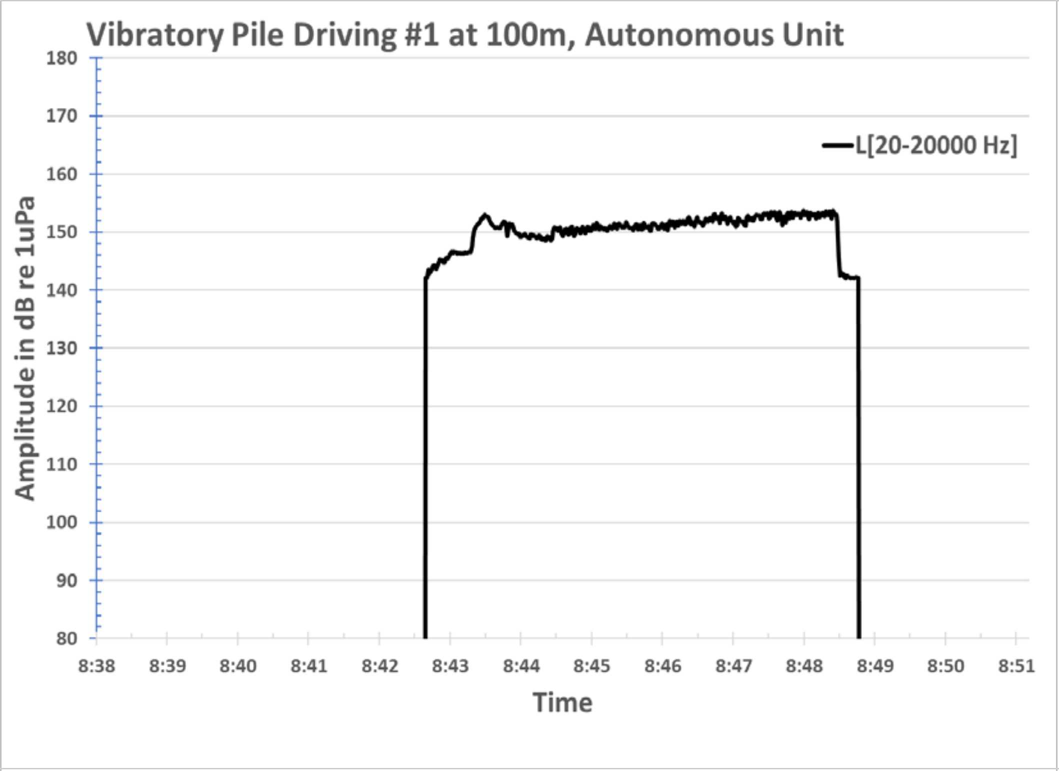


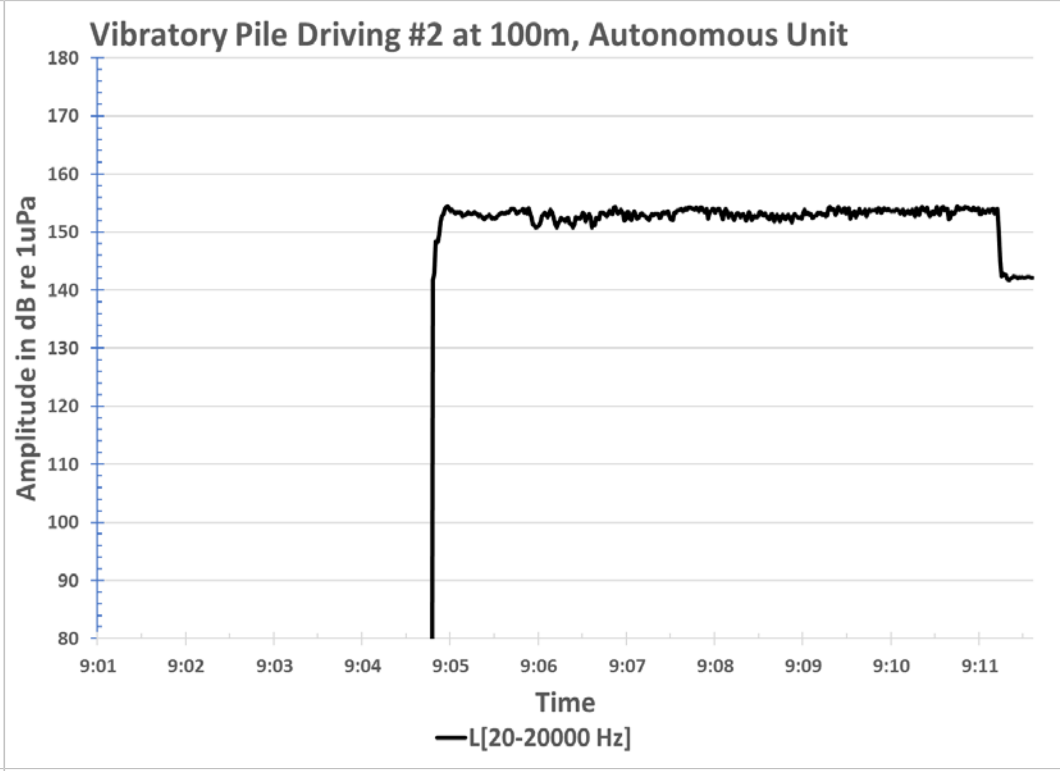
Vibratory Pile Driving #3 at 4.7km, Shallow Hydrophone
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
9:54
9:55
9:56
9:57
9:58
9:59
10:00
10:01
10:02
Time
L[20-20000 Hz]

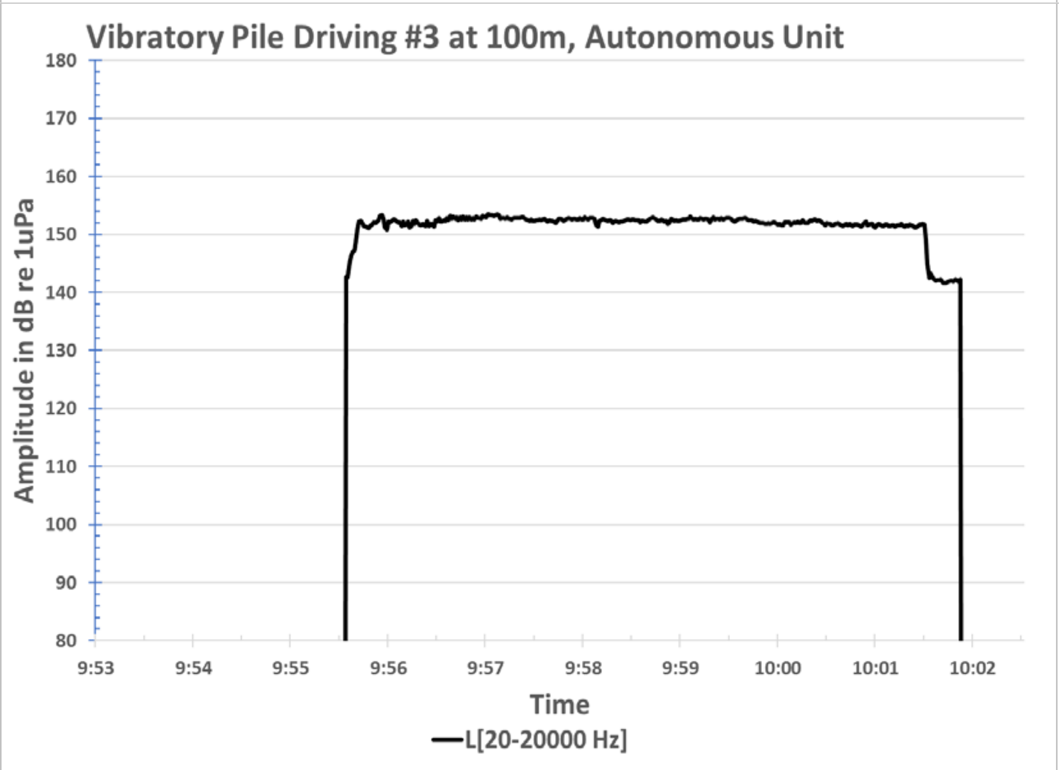


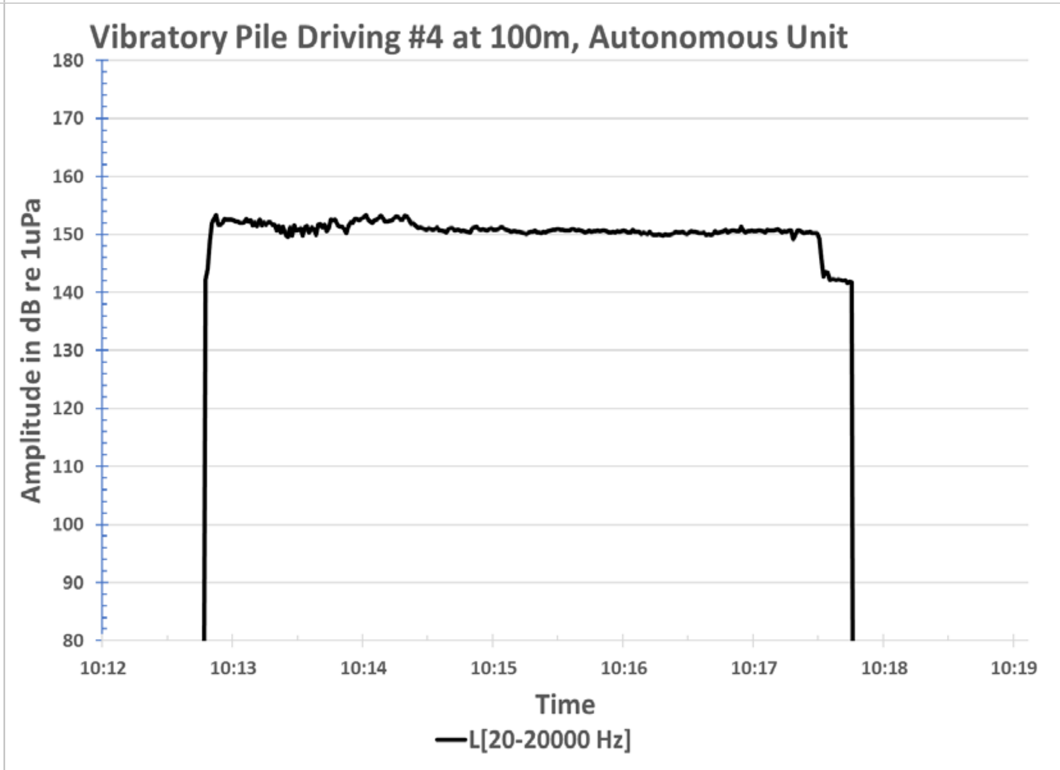
Vibratory Pile Driving #3 at 4.7km, Deep Hydrophone
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
9:54
9:55
9:56
9:57
9:58
9:59
10:00
10:01
10:02
Time
L[20-20000 Hz]

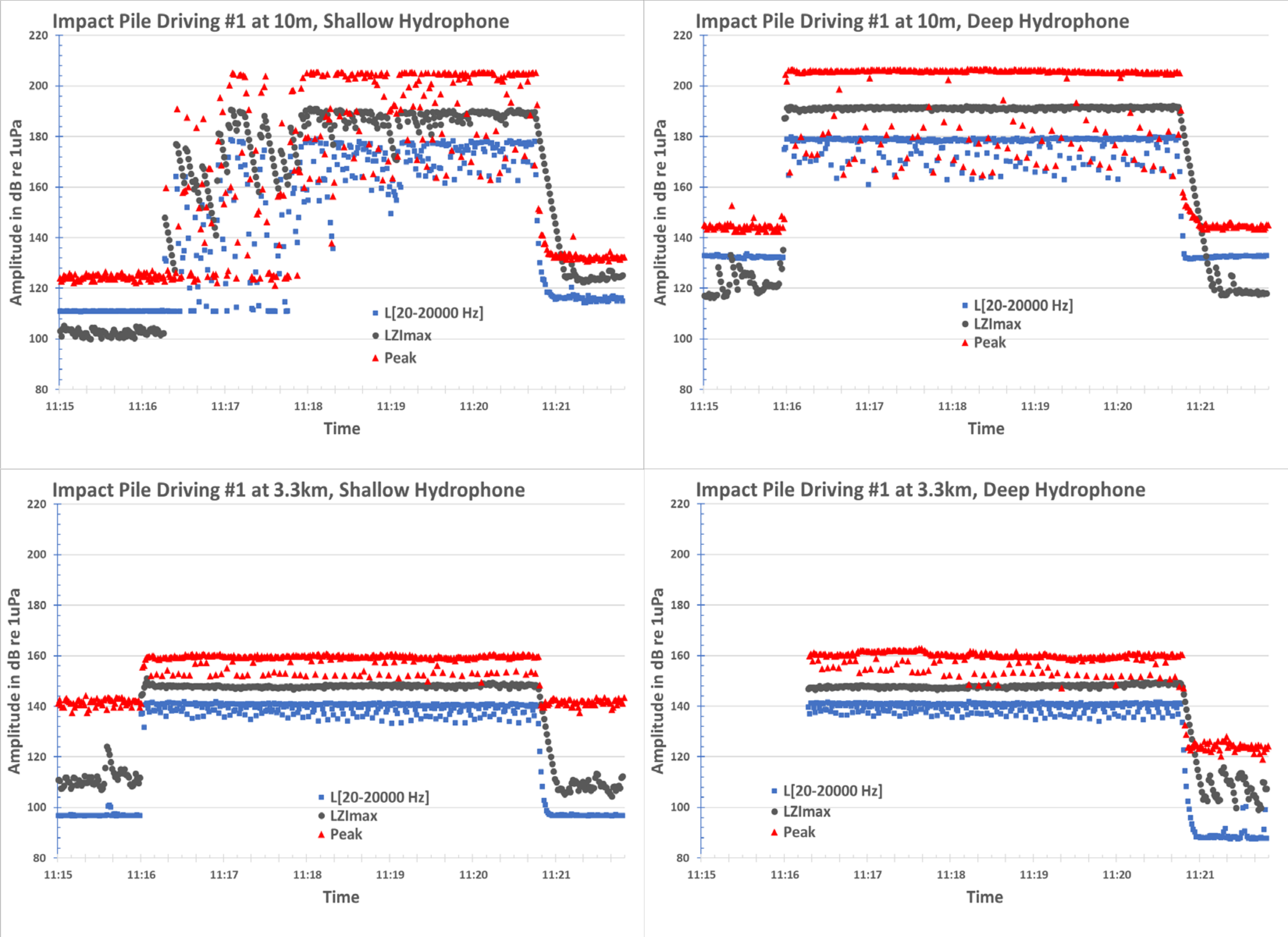

Vibratory Pile Driving #4 at 10m, Shallow Hydrophone
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
10:12
10:13
10:14
10:15
10:16
10:17
10:18
10:19
Time
L[20-20000 Hz]

Vibratory Pile Driving #4 at 10m, Deep Hydrophone
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
10:12
10:13
10:14
10:15
10:16
10:17
10:18
10:19
Time
L[20-20000 Hz]

Vibratory Pile Driving #4 at 7km, Shallow Hydrophone
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
10:12
10:13
10:14
10:15
10:16
10:17
10:18
10:19
Time
L[20-20000 Hz]

Vibratory Pile Driving #4 at 7km, Deep Hydrophone
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
10:12
10:13
10:14
10:15
10:16
10:17
10:18
10:19
Time
L[20-20000 Hz]

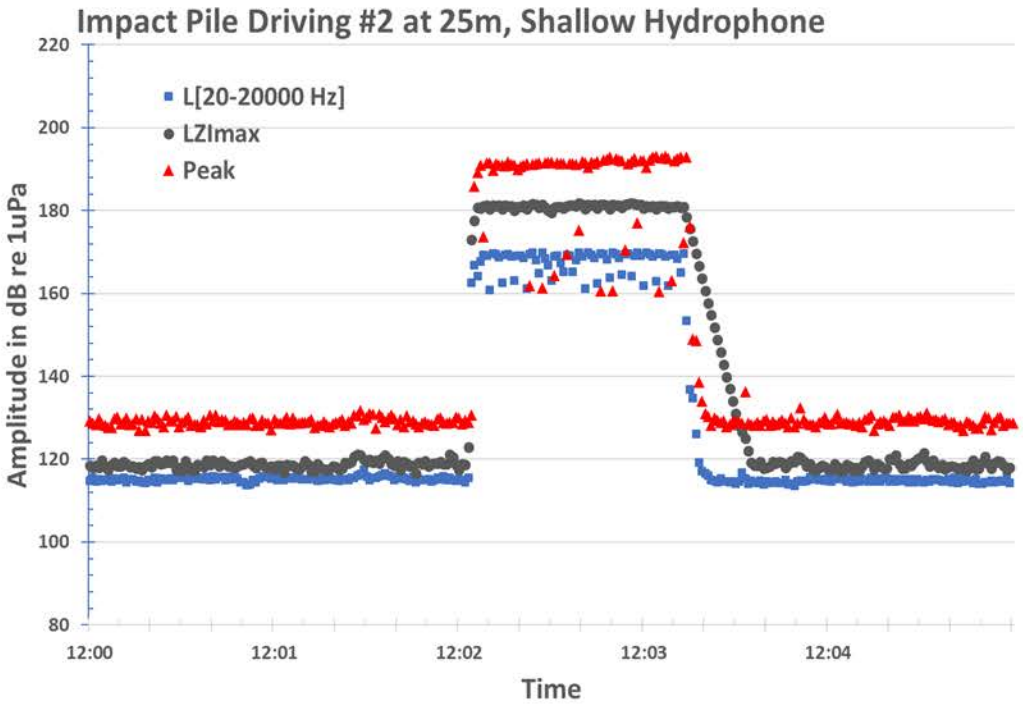

Vibratory Pile Driving #1 at 100m, Autonomous Unit
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
8:38
8:39
8:40
8:41
8:42
8:43
8:44
8:45
8:46
8:47
8:48
8:49
8:50
8:51
Time
L[20-20000 Hz]

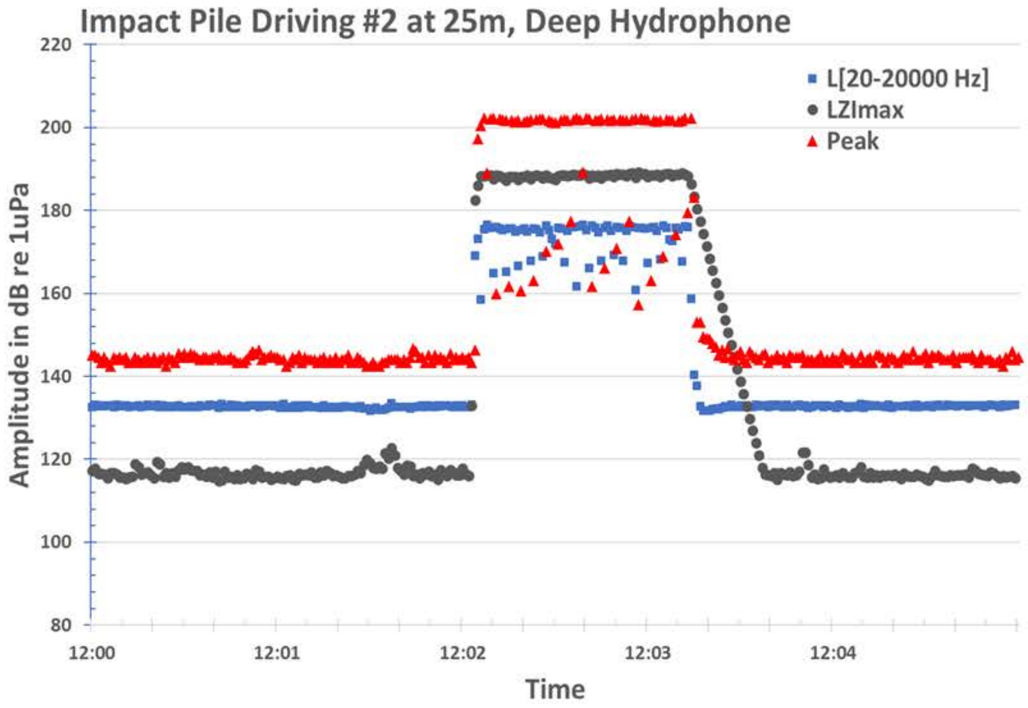

Vibratory Pile Driving #2 at 100m, Autonomous Unit
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
9:01
9:02
9:03
9:04
9:05
9:06
9:07
9:08
9:09
9:10
9:11
Time
L[20-20000 Hz]

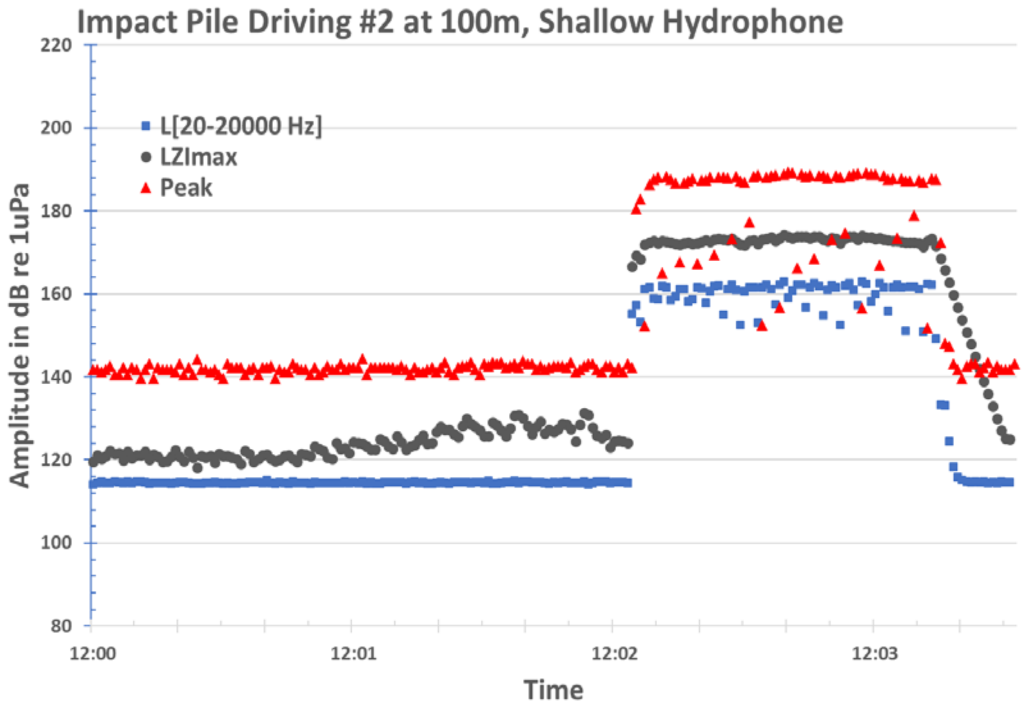

Vibratory Pile Driving #3 at 100m, Autonomous Unit
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
9:53
9:54
9:55
9:56
9:57
9:58
9:59
10:00
10:01
10:02
Time
L[20-20000 Hz]

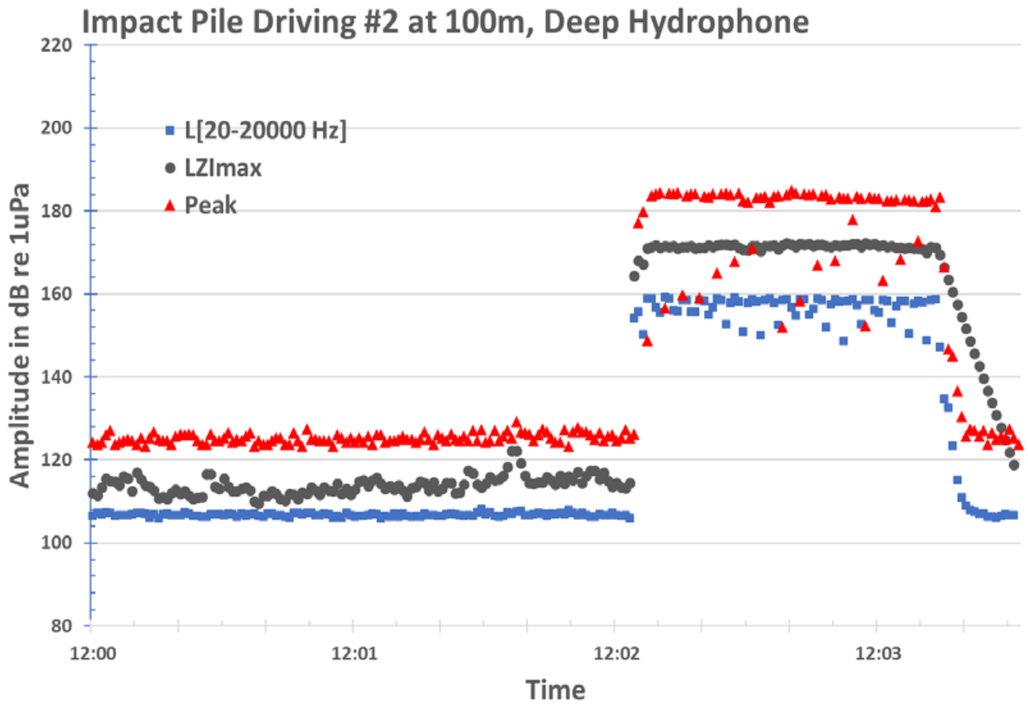

Vibratory Pile Driving #4 at 100m, Autonomous Unit
Amplitude in dB re 1uPa
180
170
160
150
140
130
120
110
100
90
80
10:12
10:13
10:14
10:15
10:16
10:17
10:18
10:19
Time
L[20-20000 Hz]

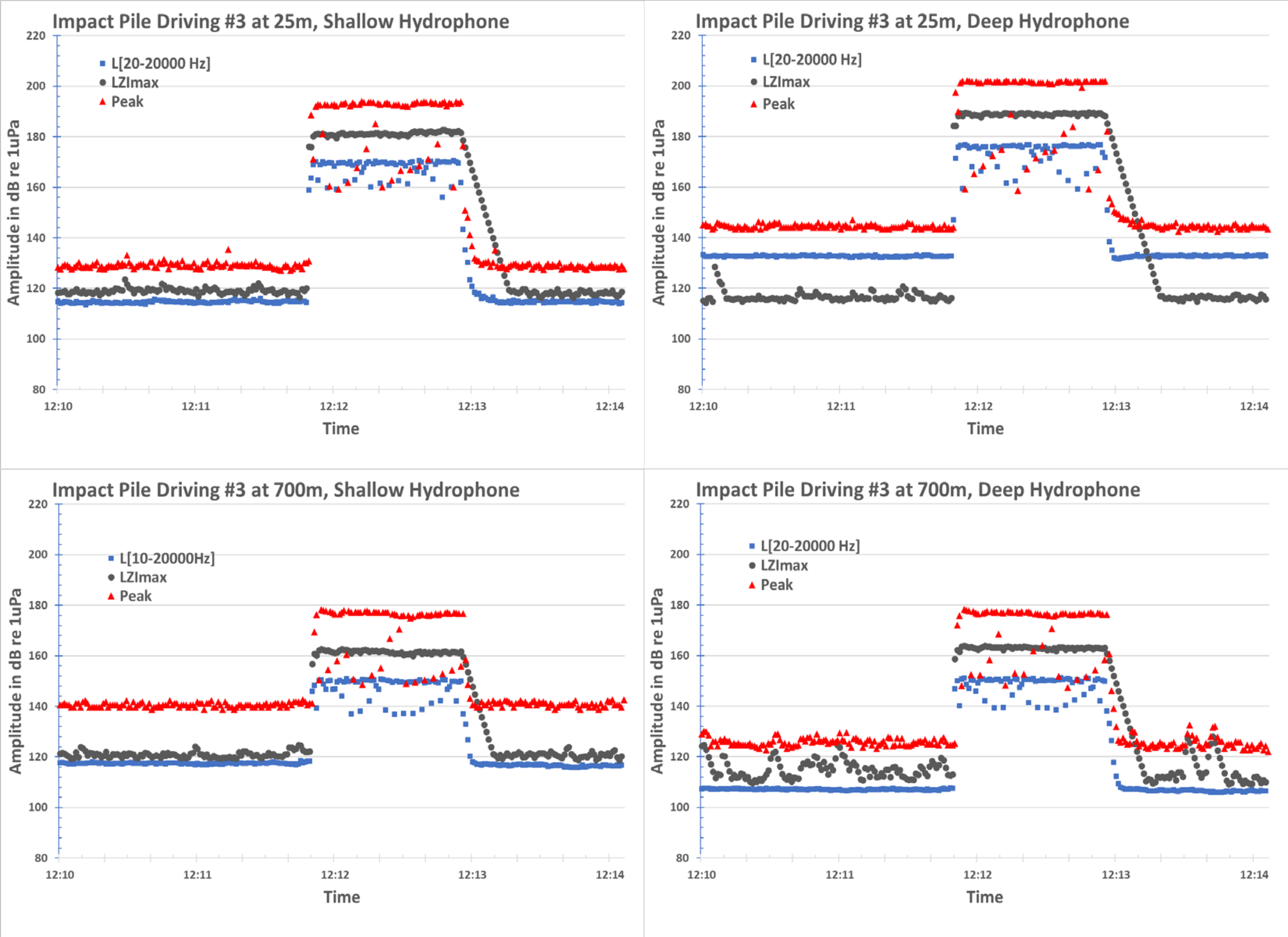

Impact Pile Driving #1 at 10m, Shallow Hydrophone
Impact Pile Driving #1 at 10m, Deep Hydrophone
Impact Pile Driving #1 at 3.3km, Shallow Hydrophone
Impact Pile Driving #1 at 3.3km, Deep Hydrophone
Amplitude in dB re 1uPa
Time
L[20-20000 Hz]
LZImax
Peak
220
200
180
160
140
120
100
80
11:15
11:16
11:17
11:18
11:19
11:20
11:21

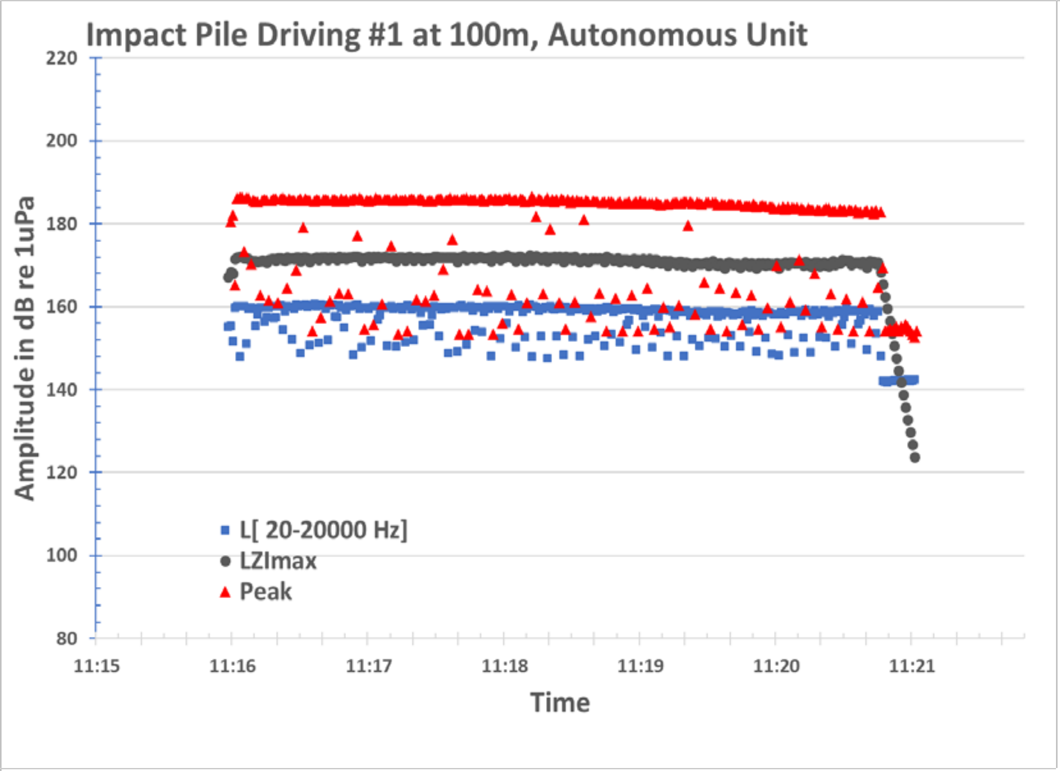

Impact Pile Driving #2 at 25m, Shallow Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
12:00
12:01
12:02
12:03
12:04
Time

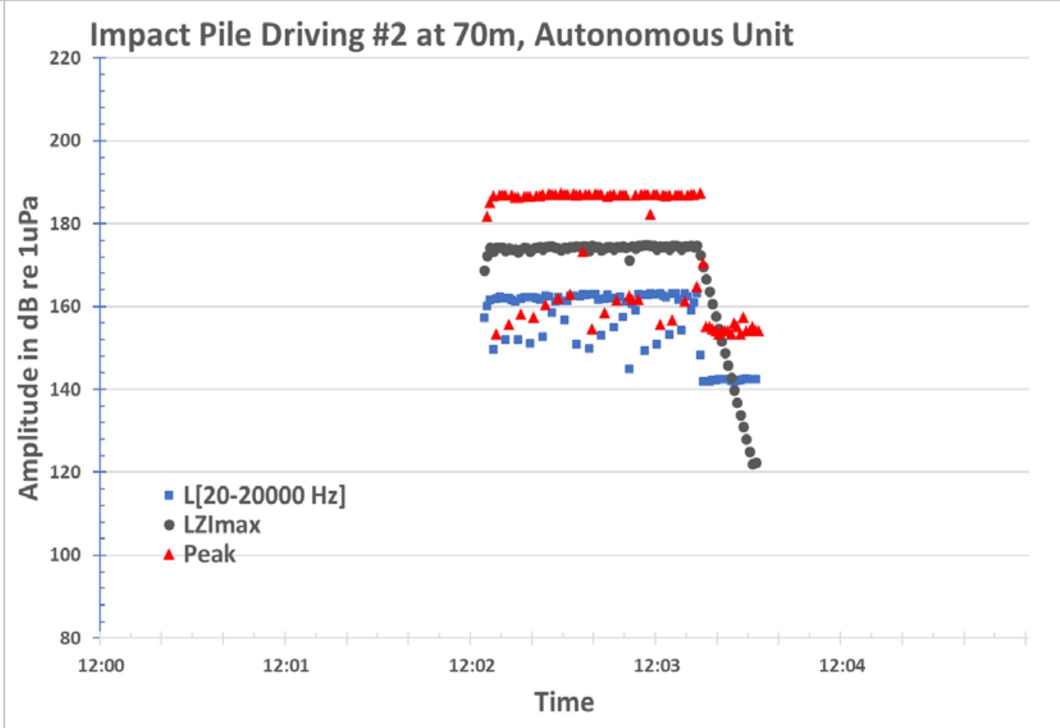

Impact Pile Driving #2 at 25m, Deep Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
12:00
12:01
12:02
12:03
12:04
Time

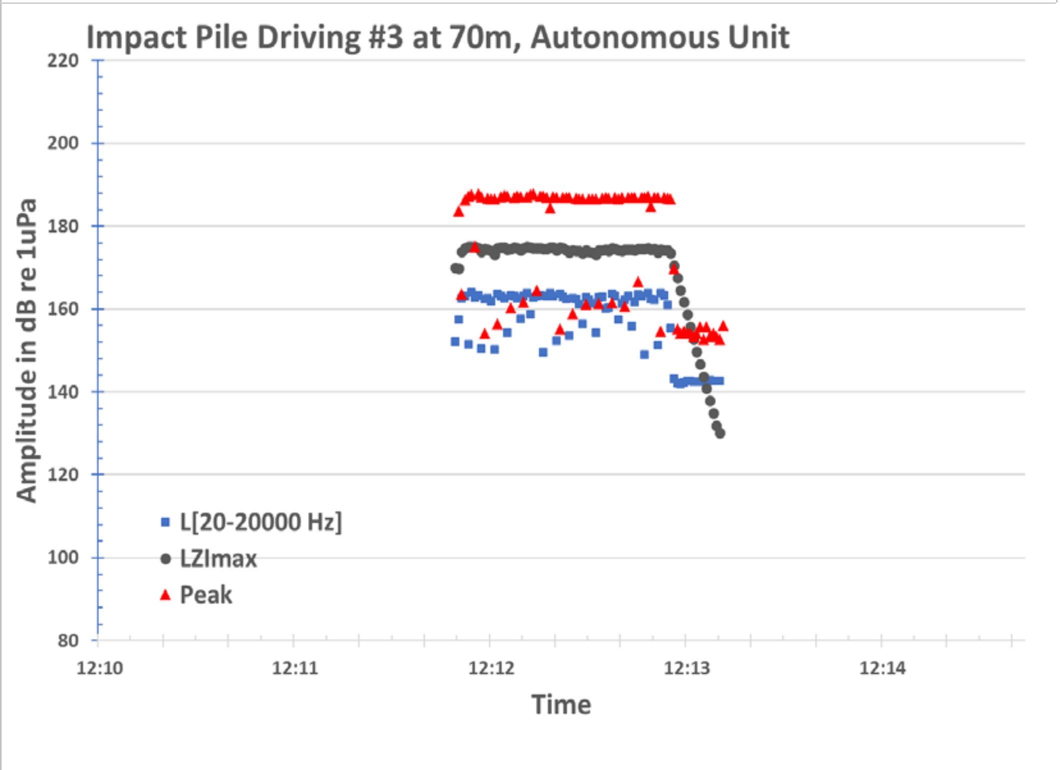

Impact Pile Driving #2 at 100m, Shallow Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
12:00
12:01
12:02
12:03
Time

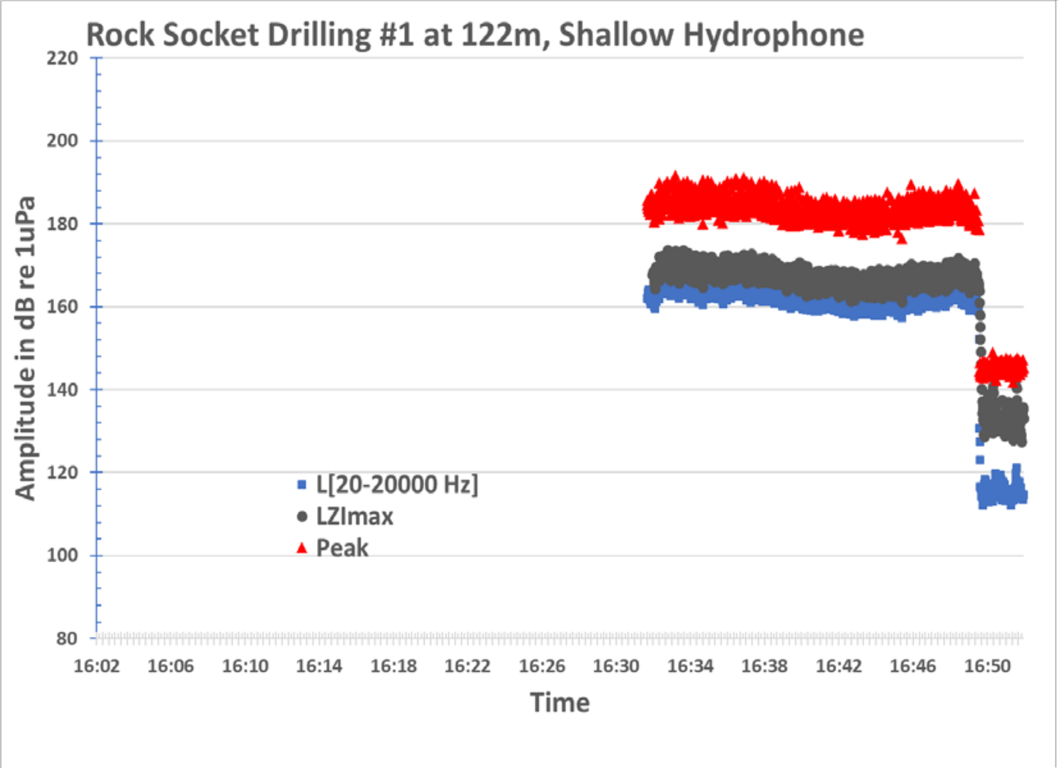

Impact Pile Driving #2 at 100m, Deep Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
12:00
12:01
12:02
12:03
Time


Impact Pile Driving #3 at 25m, Shallow Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
12:10
12:11
12:12
12:13
12:14
Time
Impact Pile Driving #3 at 25m, Deep Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
12:10
12:11
12:12
12:13
12:14
Time
Impact Pile Driving #3 at 700m, Shallow Hydrophone
L[10-20000Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
12:10
12:11
12:12
12:13
12:14
Time
Impact Pile Driving #3 at 700m, Deep Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
12:10
12:11
12:12
12:13
12:14
Time

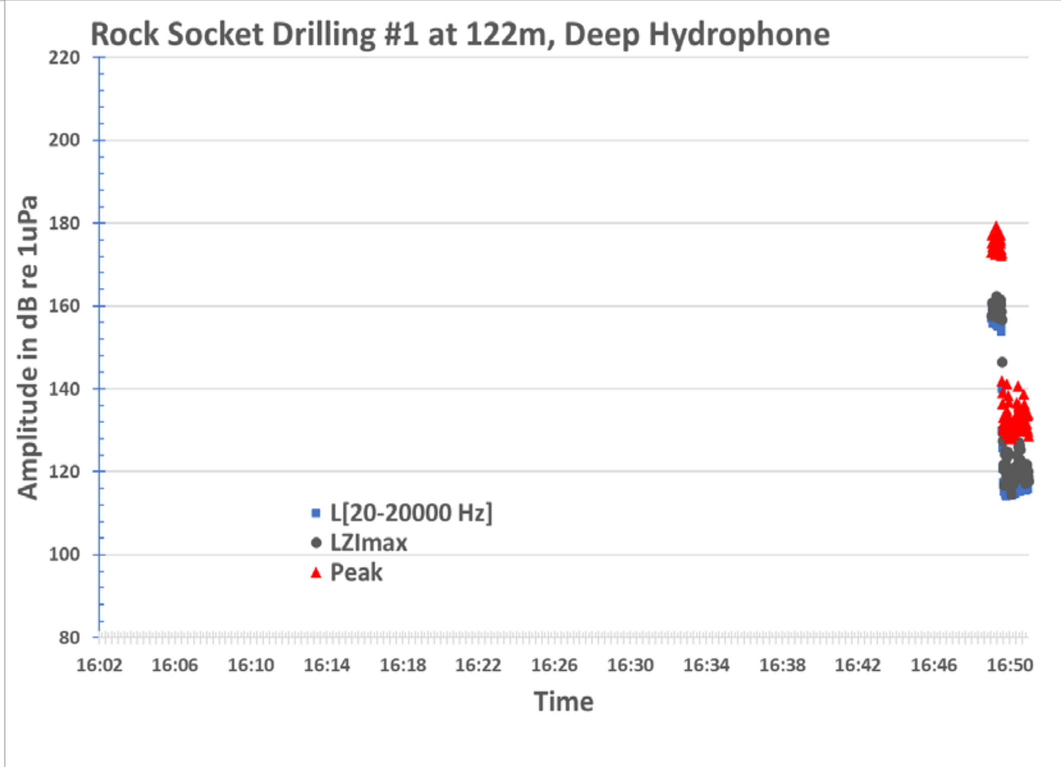

Impact Pile Driving #1 at 100m, Autonomous Unit
Amplitude in dB re 1uPa
Time
L[20-20000 Hz]
LZImax
Peak
220
200
180
160
140
120
100
80
11:15
11:16
11:17
11:18
11:19
11:20
11:21


Impact Pile Driving #2 at 70m, Autonomous Unit
Amplitude in dB re 1uPa
Time
L[20-20000 Hz]
LZImax
Peak
220
200
180
160
140
120
100
80
12:00
12:01
12:02
12:03
12:04

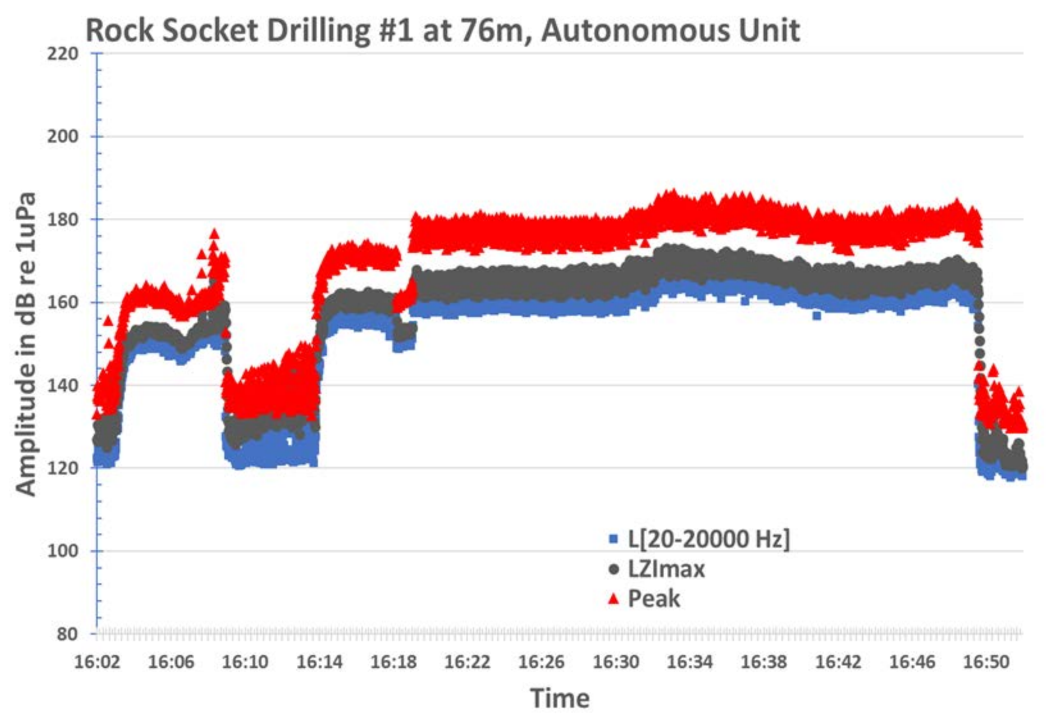

Impact Pile Driving #3 at 70m, Autonomous Unit
Amplitude in dB re 1uPa
Time
L[20-20000 Hz]
LZImax
Peak
220
200
180
160
140
120
100
80
12:10
12:11
12:12
12:13
12:14



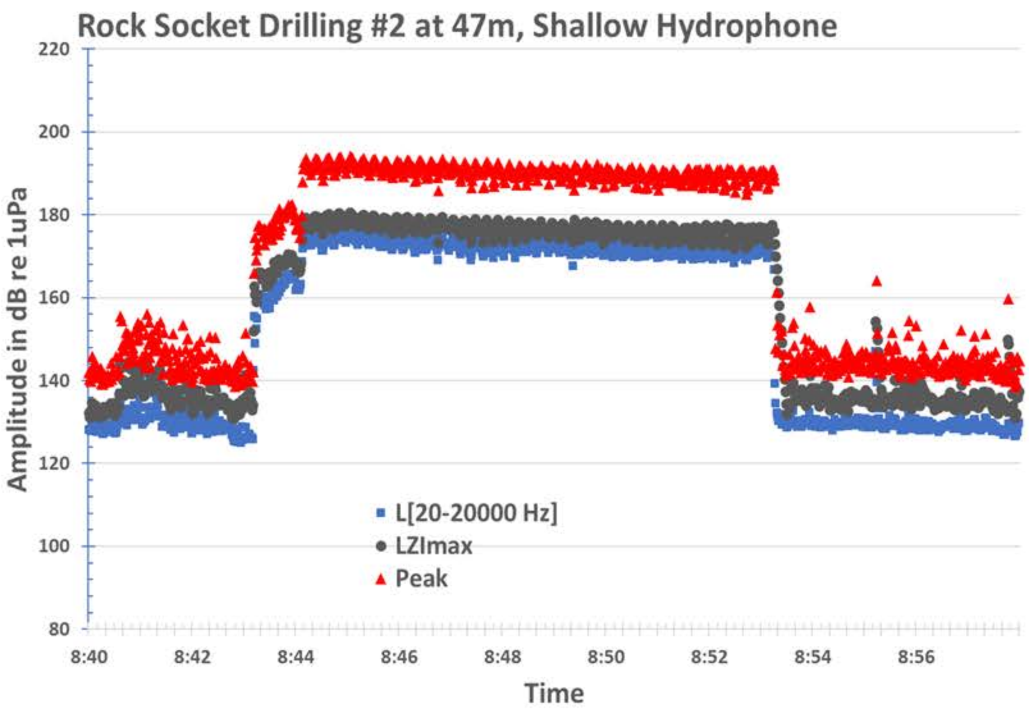
Rock Socket Drilling #1 at 122m, Shallow Hydrophone
220
200
180
160
140
120
100
80
Amplitude in dB re 1uPa
L[20-20000 Hz]
LZImax
Peak
16:02
16:06
16:10
16:14
16:18
16:22
16:26
16:30
16:34
16:38
16:42
16:46
16:50
Time

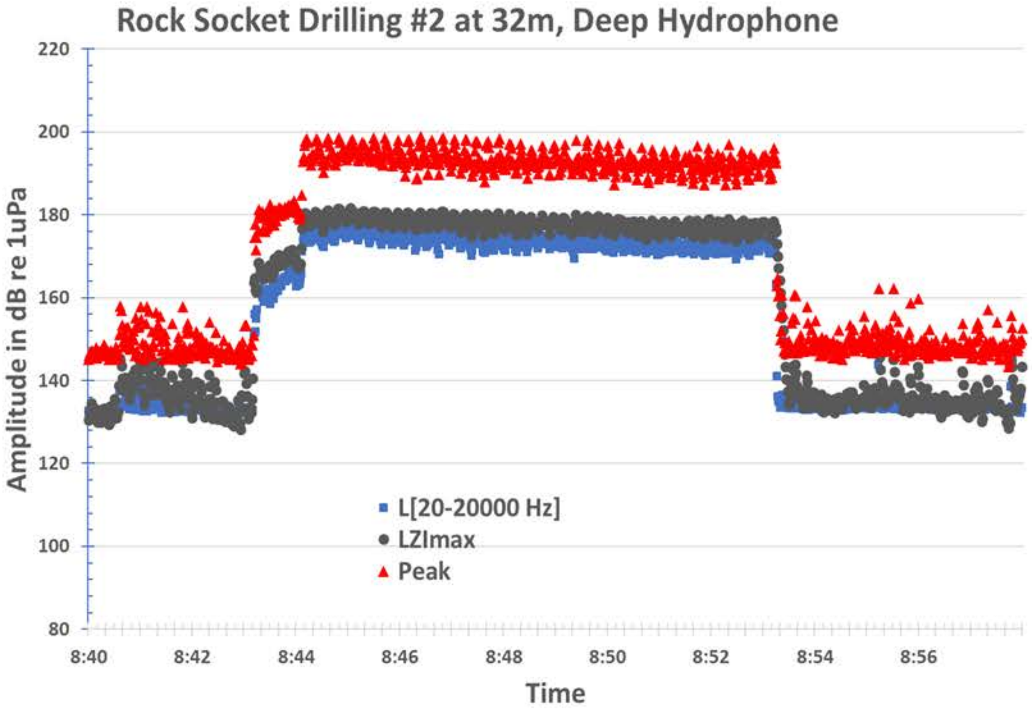


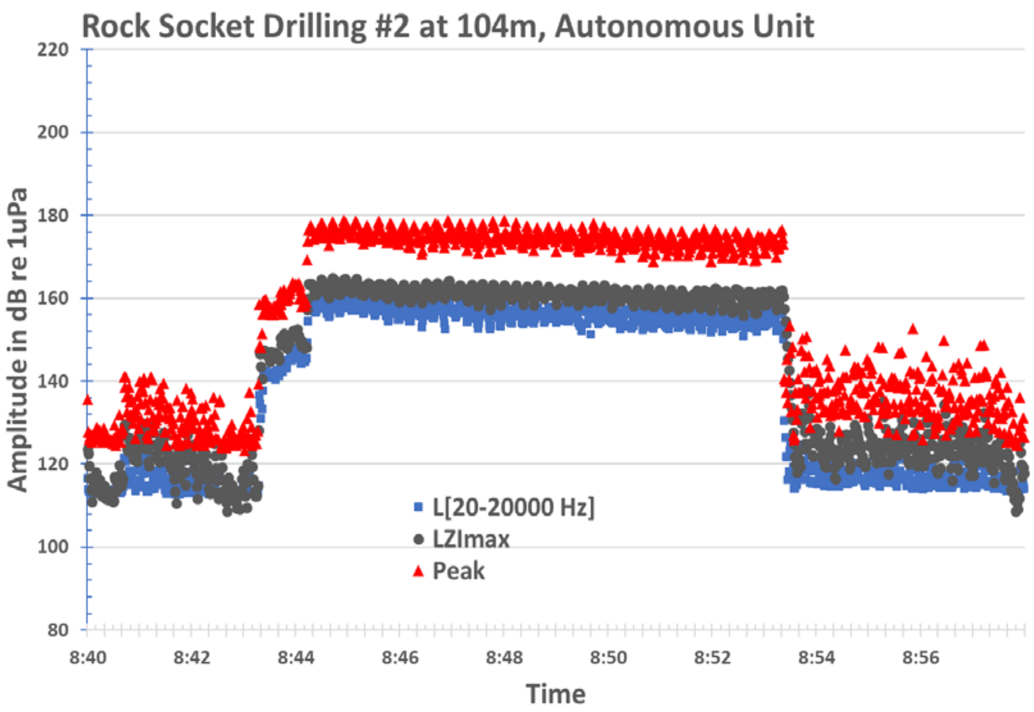
Rock Socket Drilling #1 at 122m, Deep Hydrophone
220
200
180
160
140
120
100
80
Amplitude in dB re 1uPa
L[20-20000 Hz]
LZImax
Peak
16:02
16:06
16:10
16:14
16:18
16:22
16:26
16:30
16:34
16:38
16:42
16:46
16:50
Time

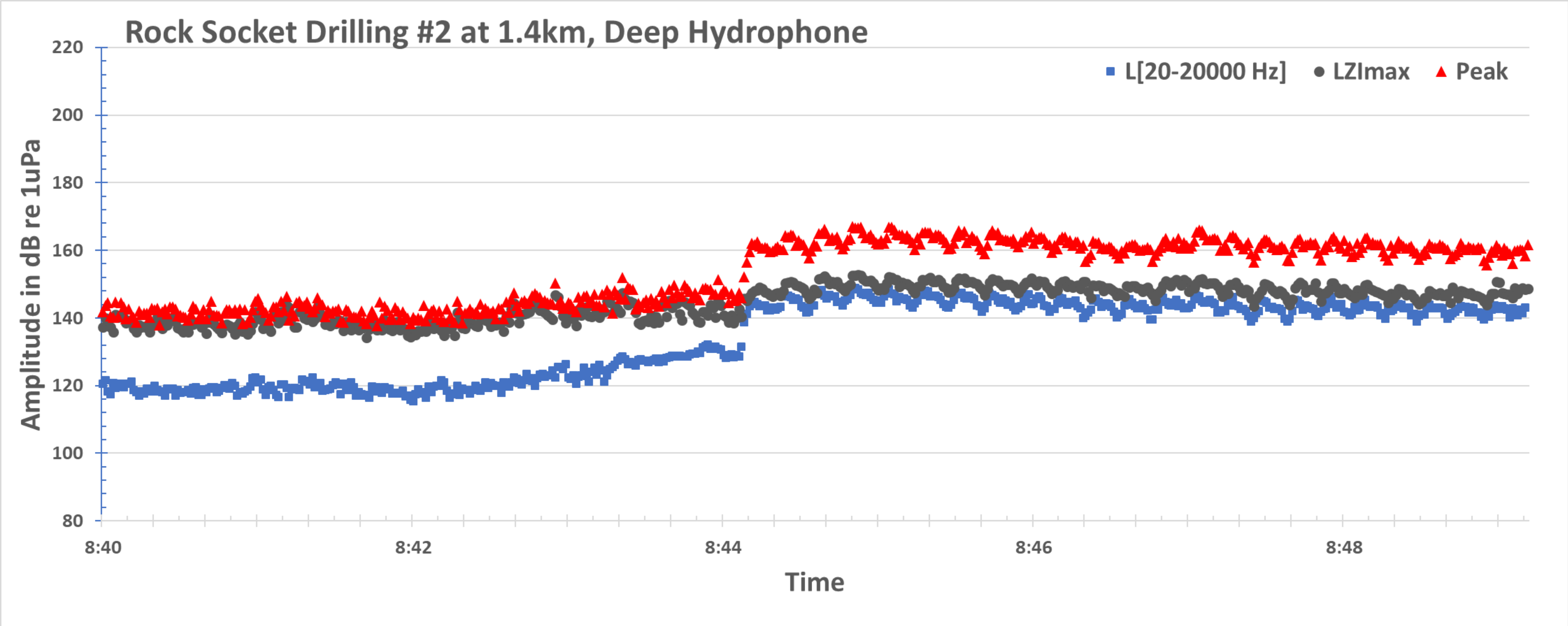


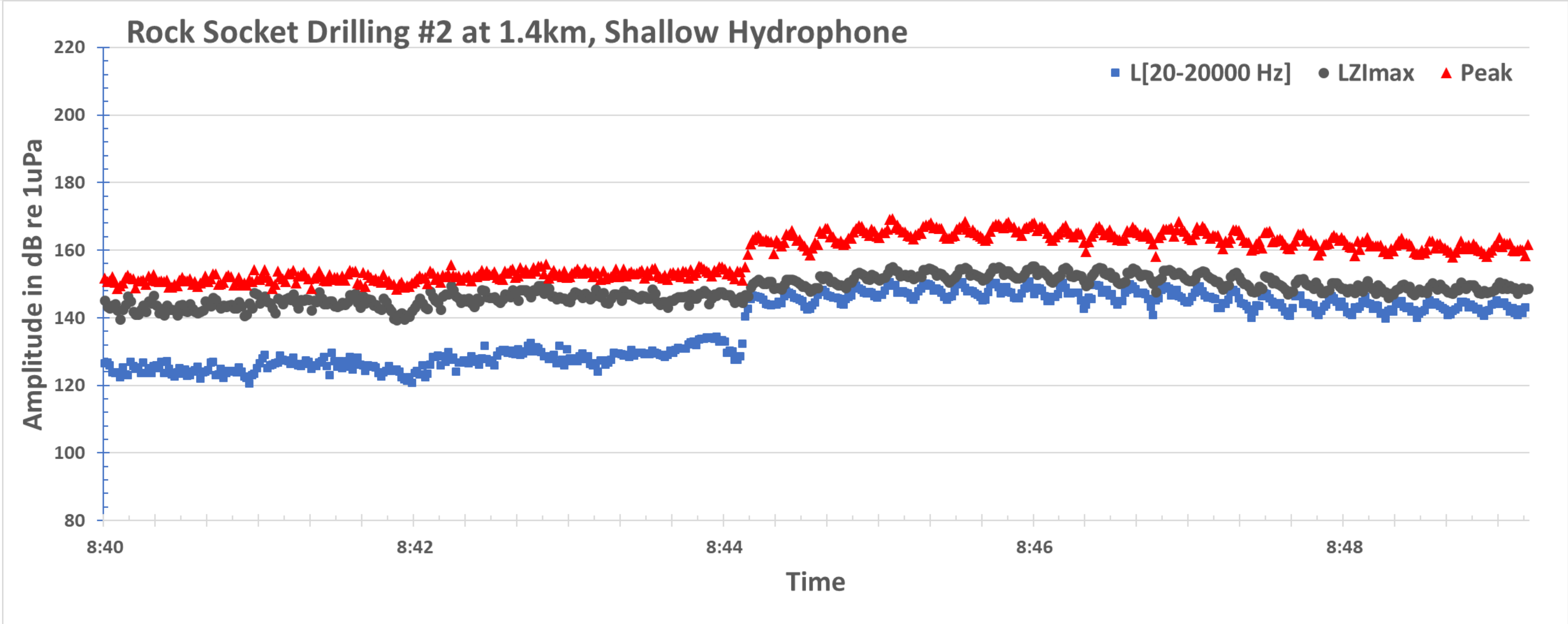
Rock Socket Drilling #1 at 76m, Autonomous Unit
220
200
180
160
140
120
100
80
Amplitude in dB re 1uPa
L[20-20000 Hz]
LZImax
Peak
16:02
16:06
16:10
16:14
16:18
16:22
16:26
16:30
16:34
16:38
16:42
16:46
16:50
Time

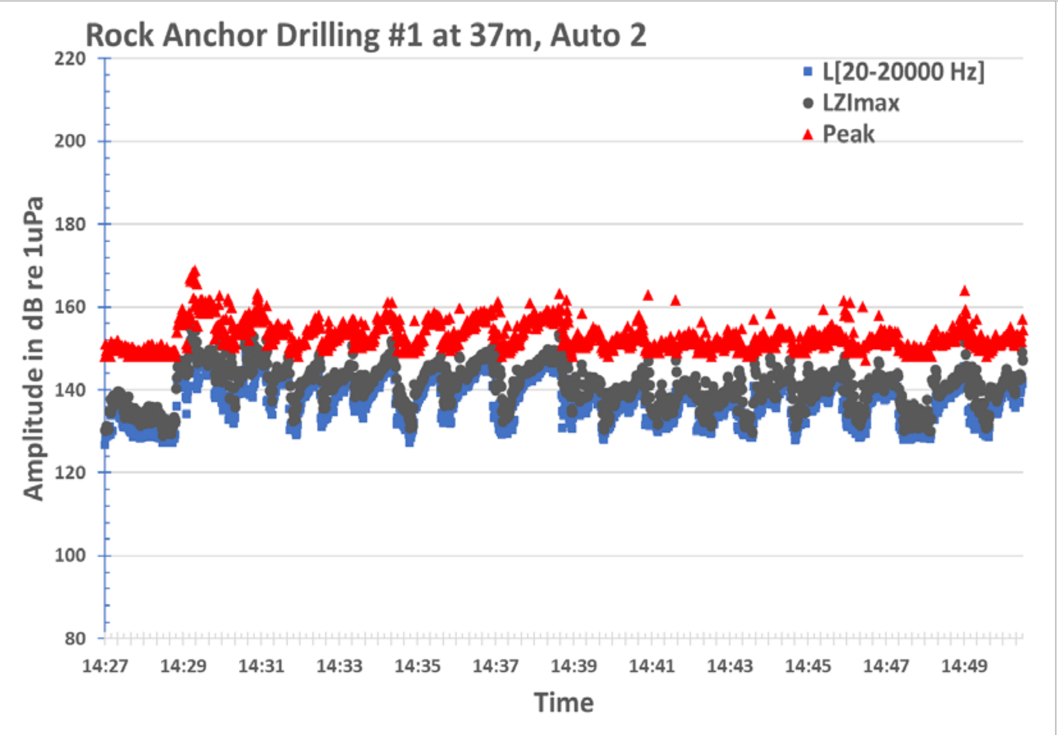

Rock Socket Drilling #2 at 47m, Shallow Hydrophone
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
8:40
8:42
8:44
8:46
8:48
8:50
8:52
8:54
8:56
Time
L[20-20000 Hz]
LZImax
Peak

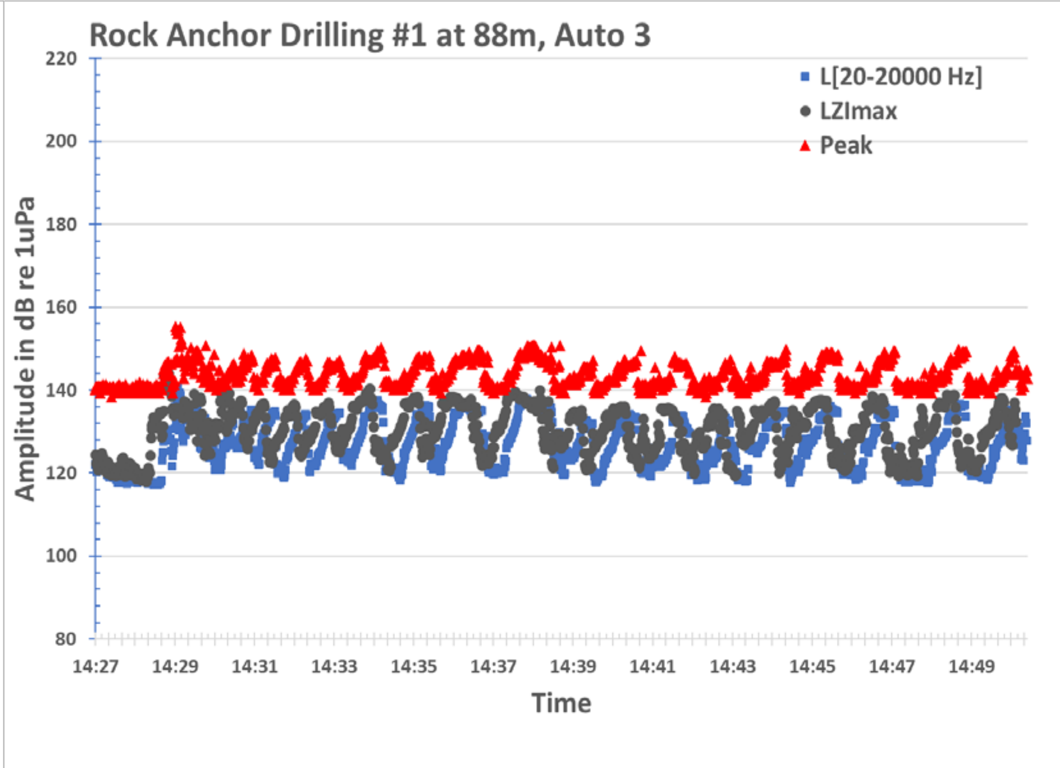

Rock Socket Drilling #2 at 32m, Deep Hydrophone
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
8:40
8:42
8:44
8:46
8:48
8:50
8:52
8:54
8:56
Time
L[20-20000 Hz]
LZImax
Peak

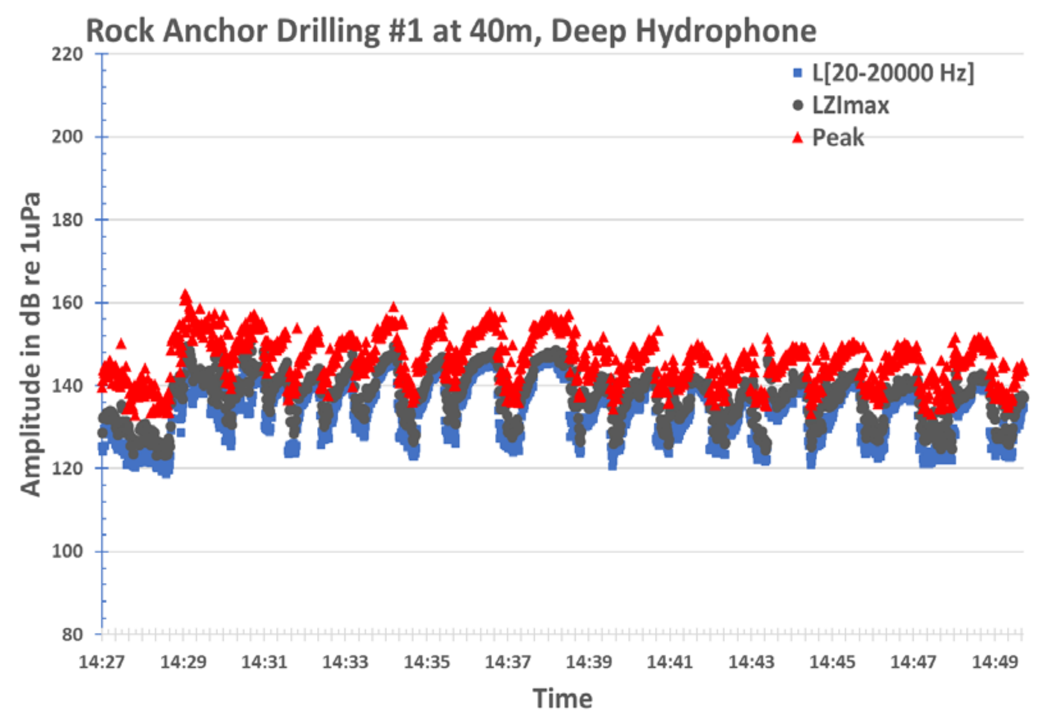

Rock Socket Drilling #2 at 104m, Autonomous Unit
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
8:40
8:42
8:44
8:46
8:48
8:50
8:52
8:54
8:56
Time
L[20-20000 Hz]
LZImax
Peak

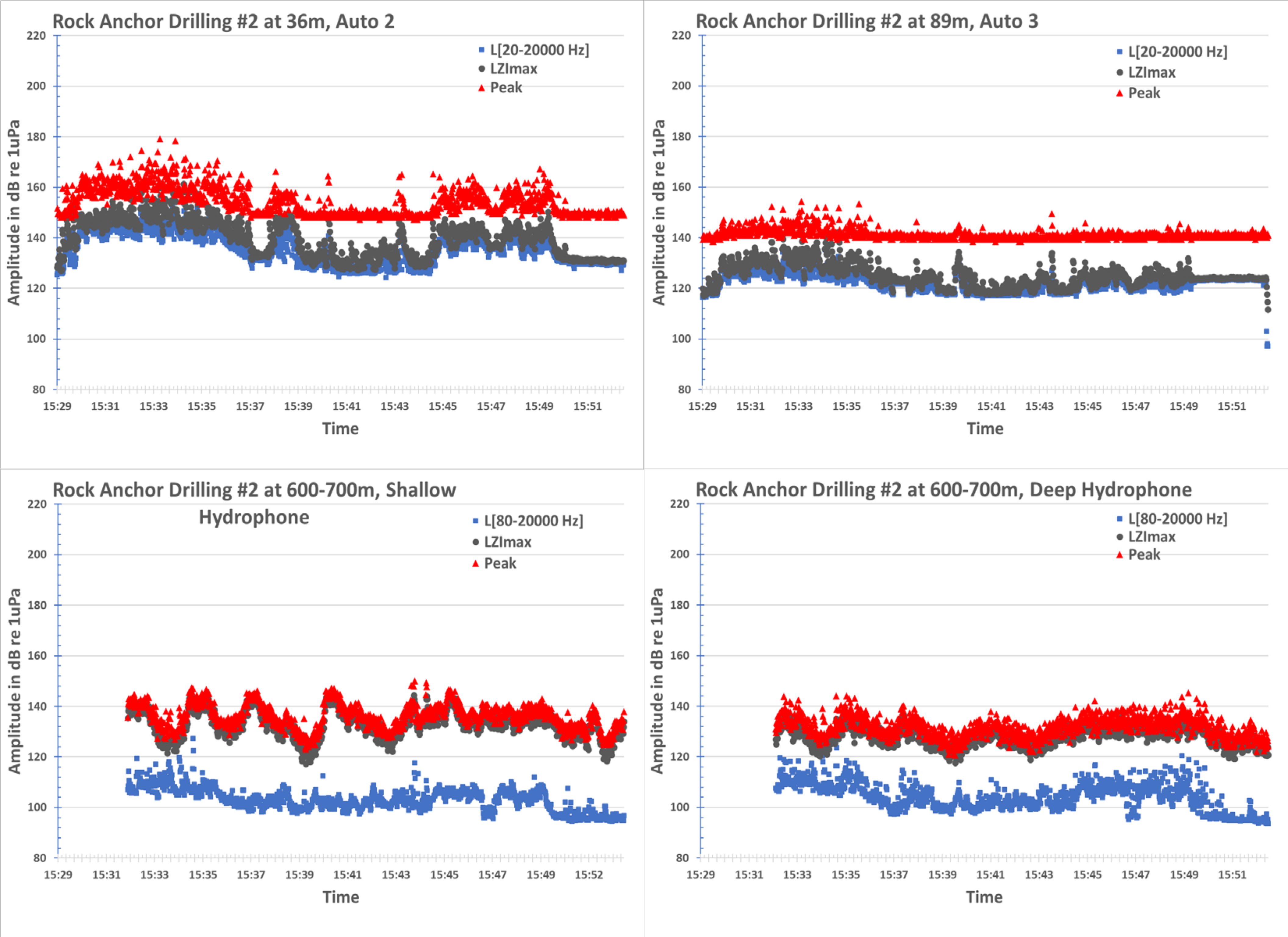

Rock Socket Drilling #2 at 1.4km, Deep Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
8:40
8:42
8:44
8:46
8:48
Time

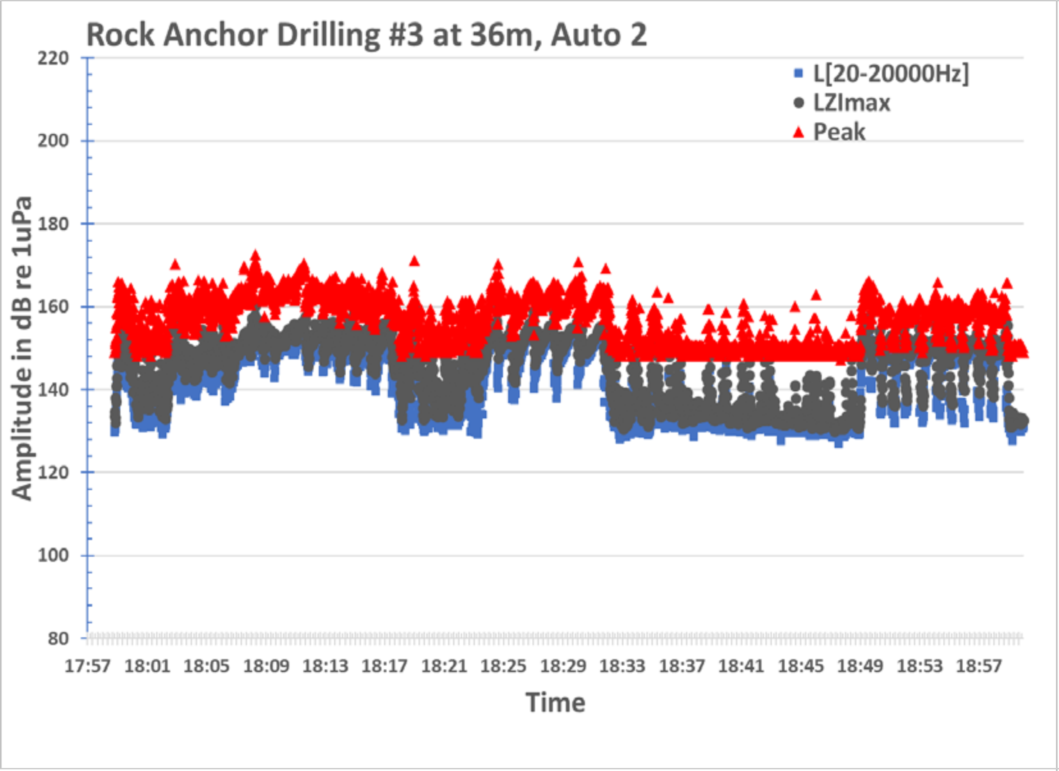

Rock Socket Drilling #2 at 1.4km, Shallow Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
8:40
8:42
8:44
8:46
8:48
Time

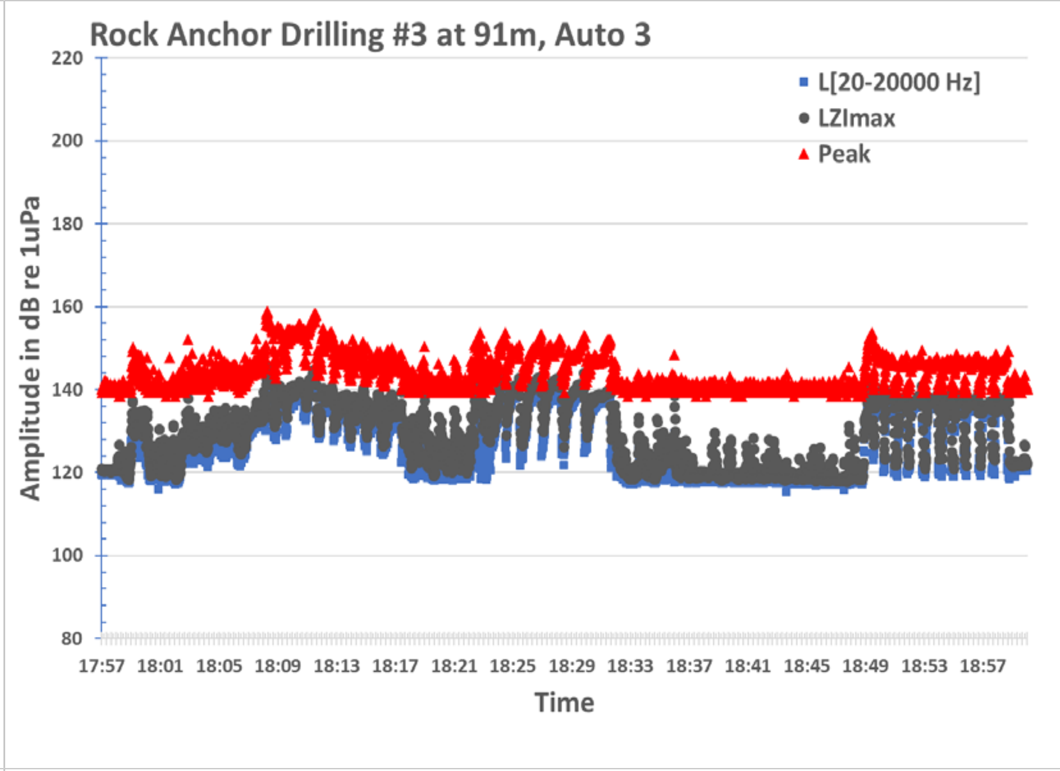

Rock Anchor Drilling #1 at 37m, Auto 2
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
14:27
14:29
14:31
14:33
14:35
14:37
14:39
14:41
14:43
14:45
14:47
14:49
Time

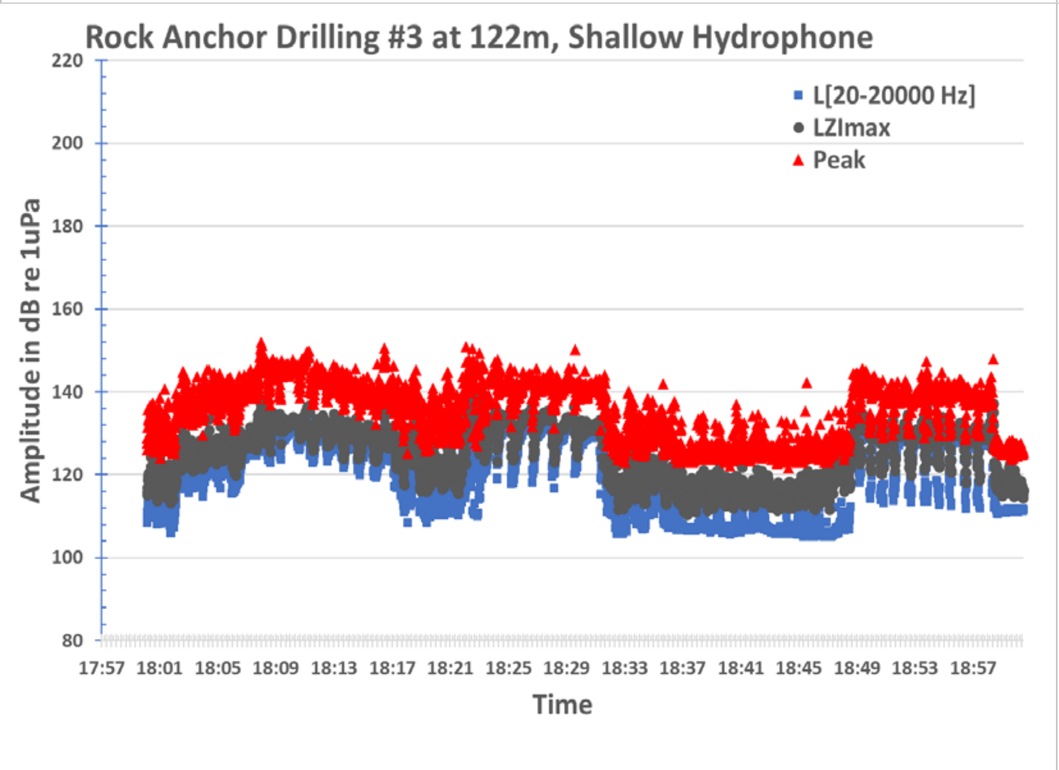

Rock Anchor Drilling #1 at 88m, Auto 3
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
14:27
14:29
14:31
14:33
14:35
14:37
14:39
14:41
14:43
14:45
14:47
14:49
Time

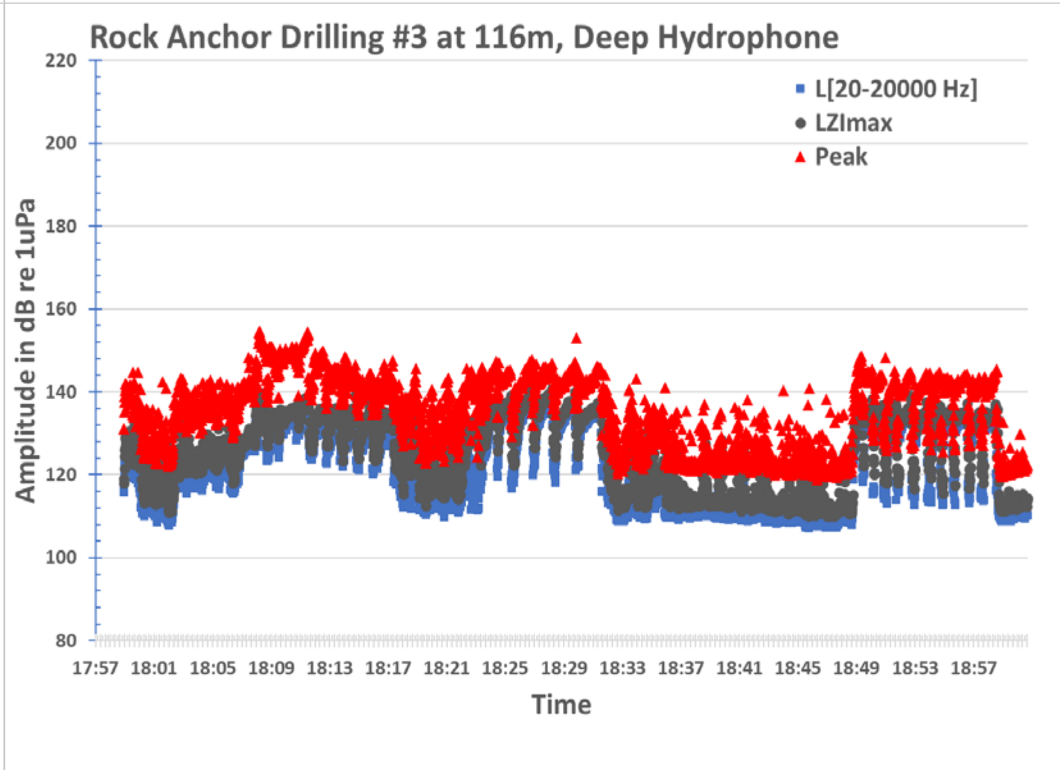

Rock Anchor Drilling #1 at 40m, Deep Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
14:27
14:29
14:31
14:33
14:35
14:37
14:39
14:41
14:43
14:45
14:47
14:49
Time

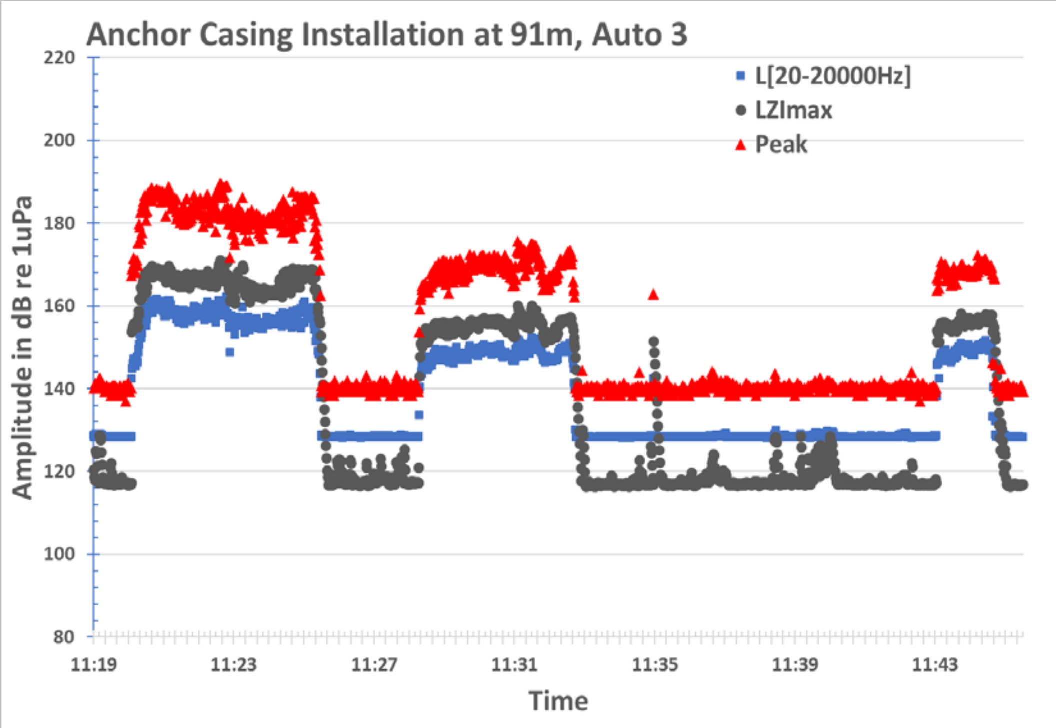

Rock Anchor Drilling #2 at 36m, Auto 2
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
15:29
15:31
15:33
15:35
15:37
15:39
15:41
15:43
15:45
15:47
15:49
15:51
Time
Rock Anchor Drilling #2 at 89m, Auto 3
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
Time
Rock Anchor Drilling #2 at 600-700m, Shallow Hydrophone
L[80-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
15:52
Time
Rock Anchor Drilling #2 at 600-700m, Deep Hydrophone
L[80-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
Time


Rock Anchor Drilling #3 at 36m, Auto 2
L[20-20000Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
17:57 18:01 18:05 18:09 18:13 18:17 18:21 18:25 18:29 18:33 18:37 18:41 18:45 18:49 18:53 18:57
Time

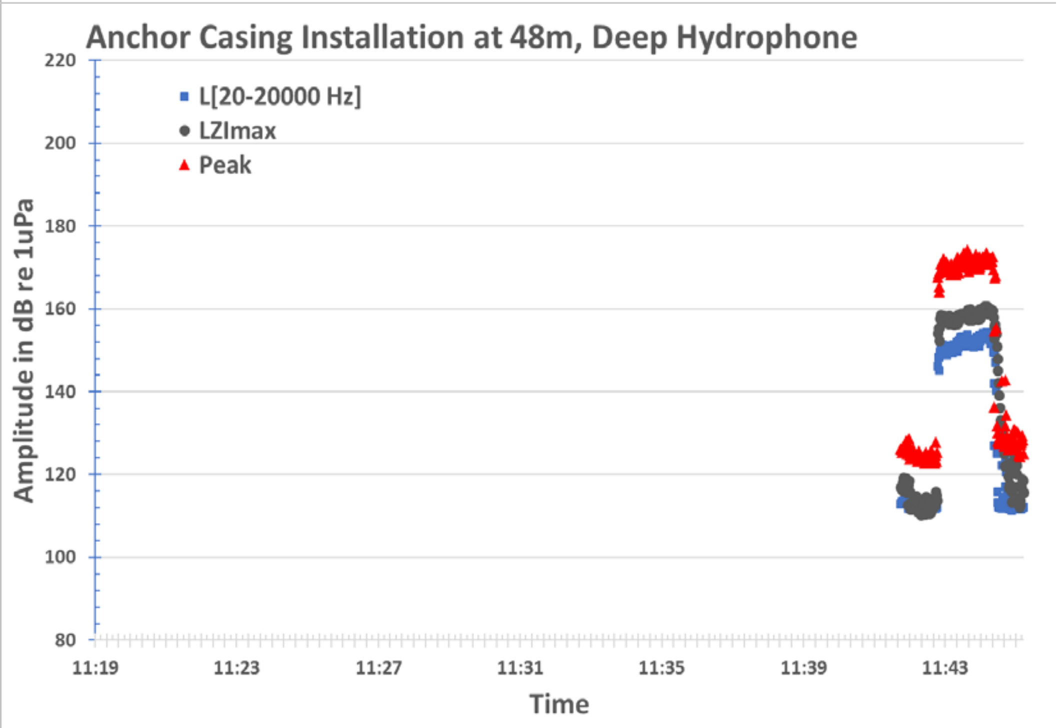

Rock Anchor Drilling #3 at 91m, Auto 3
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
17:57 18:01 18:05 18:09 18:13 18:17 18:21 18:25 18:29 18:33 18:37 18:41 18:45 18:49 18:53 18:57
Time


Rock Anchor Drilling #3 at 122m, Shallow Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
17:57 18:01 18:05 18:09 18:13 18:17 18:21 18:25 18:29 18:33 18:37 18:41 18:45 18:49 18:53 18:57
Time


Rock Anchor Drilling #3 at 116m, Deep Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
17:57 18:01 18:05 18:09 18:13 18:17 18:21 18:25 18:29 18:33 18:37 18:41 18:45 18:49 18:53 18:57
Time

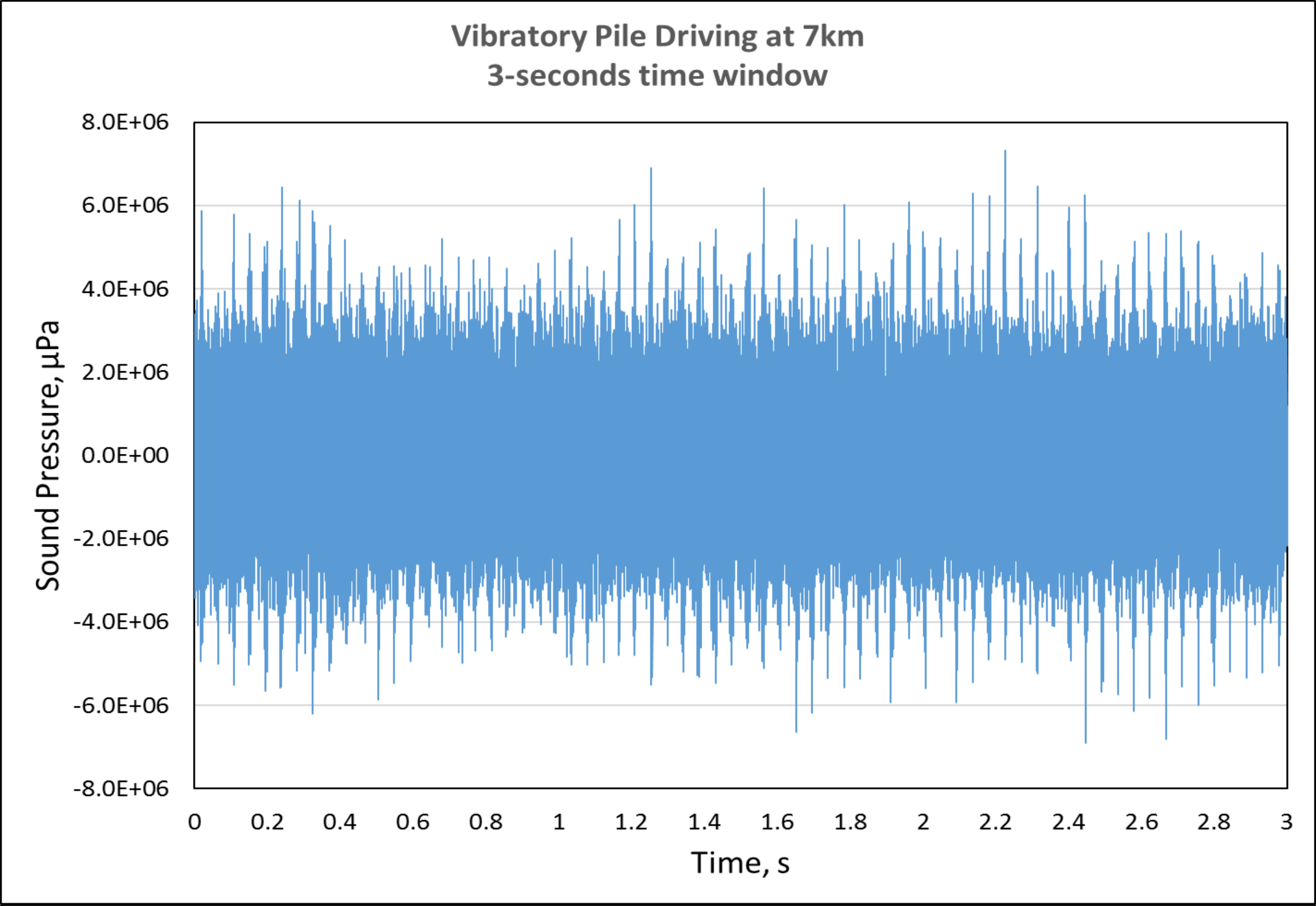


Anchor Casing Installation at 91m, Auto 3
L[20-20000Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
11:19
11:23
11:27
11:31
11:35
11:39
11:43
Time

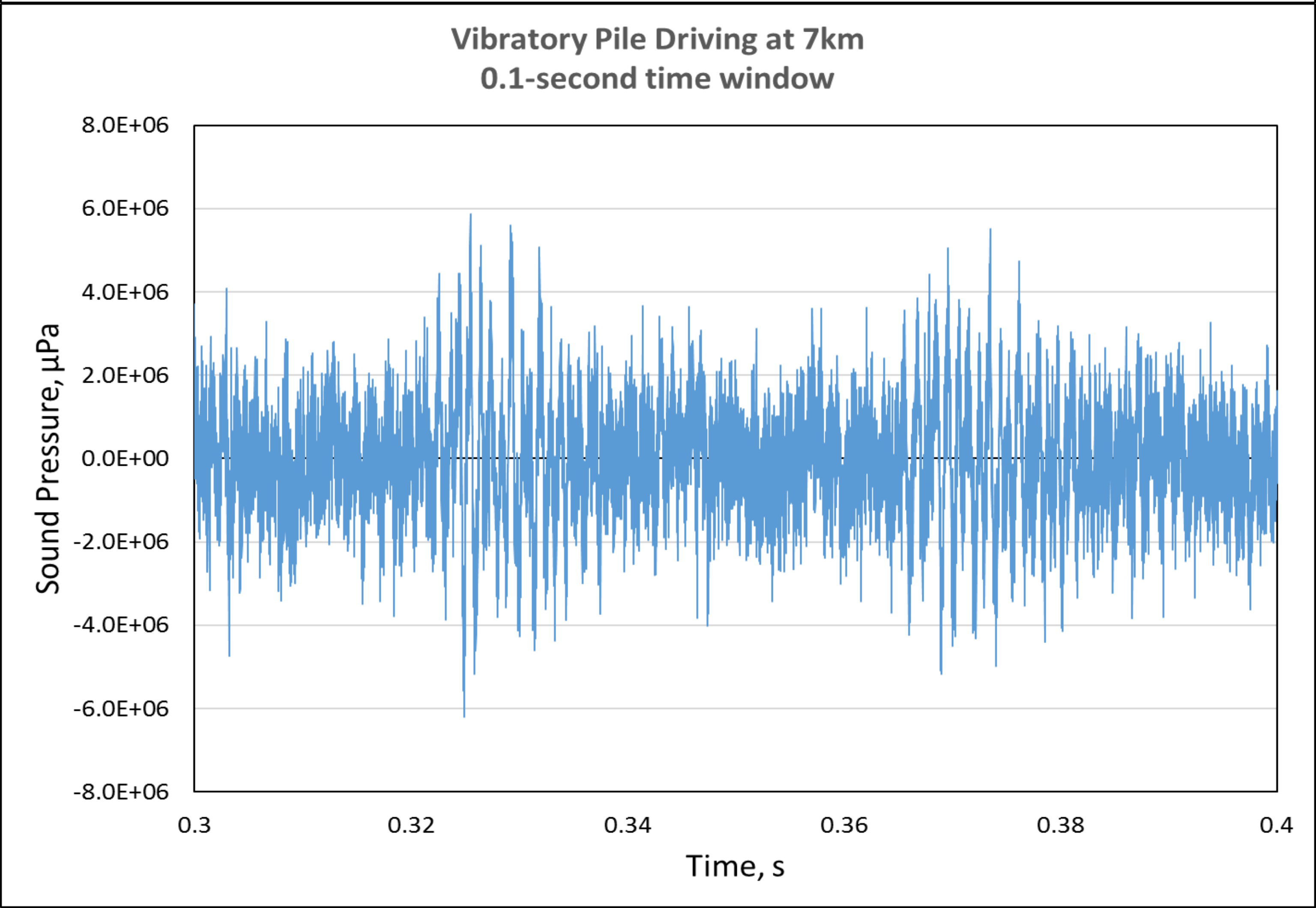


Anchor Casing Installation at 48m, Deep Hydrophone
L[20-20000 Hz]
LZImax
Peak
Amplitude in dB re 1uPa
220
200
180
160
140
120
100
80
11:19
11:23
11:27
11:31
11:35
11:39
11:43
Time

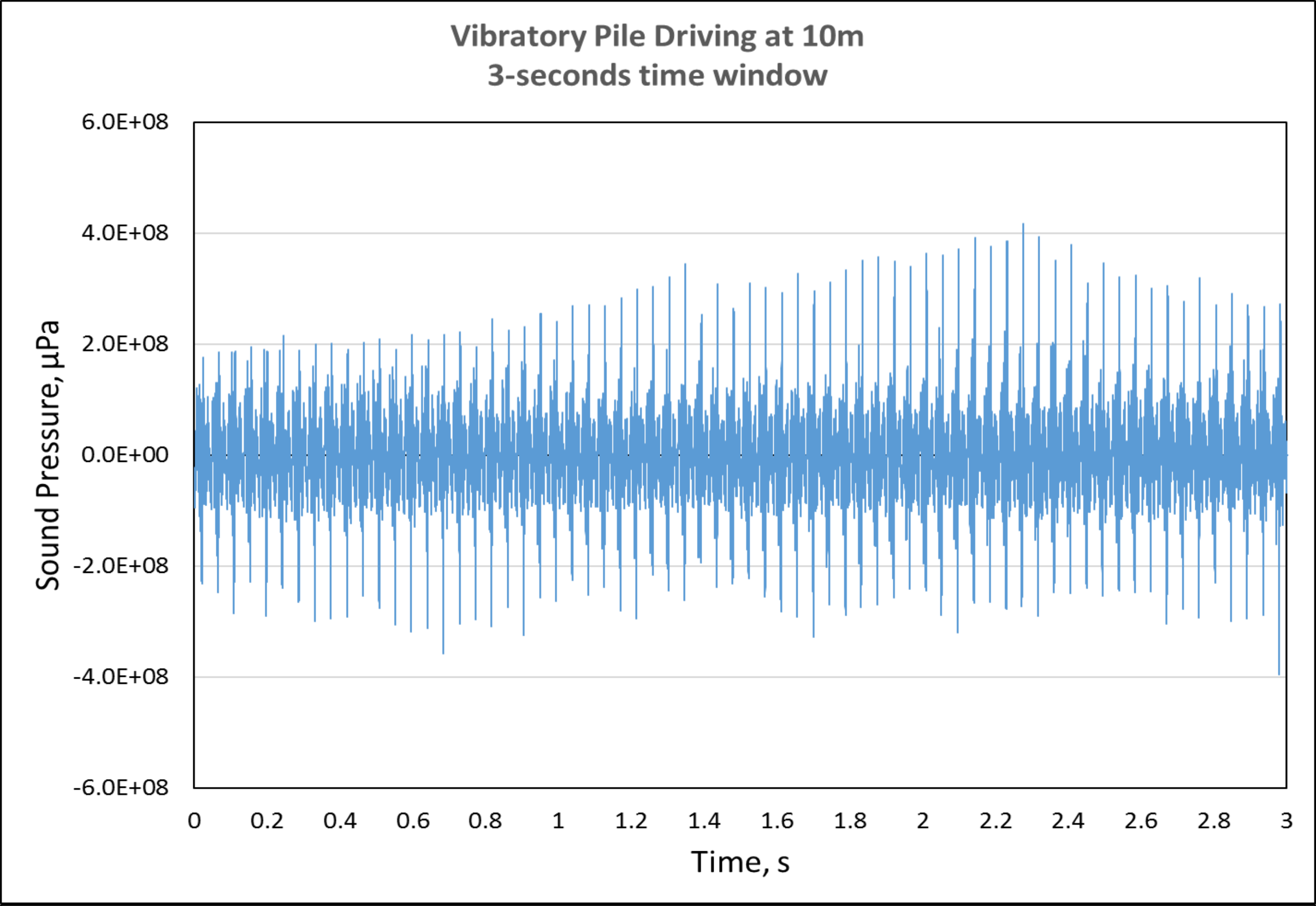
Appendix D – Pulse-Specific Waveforms

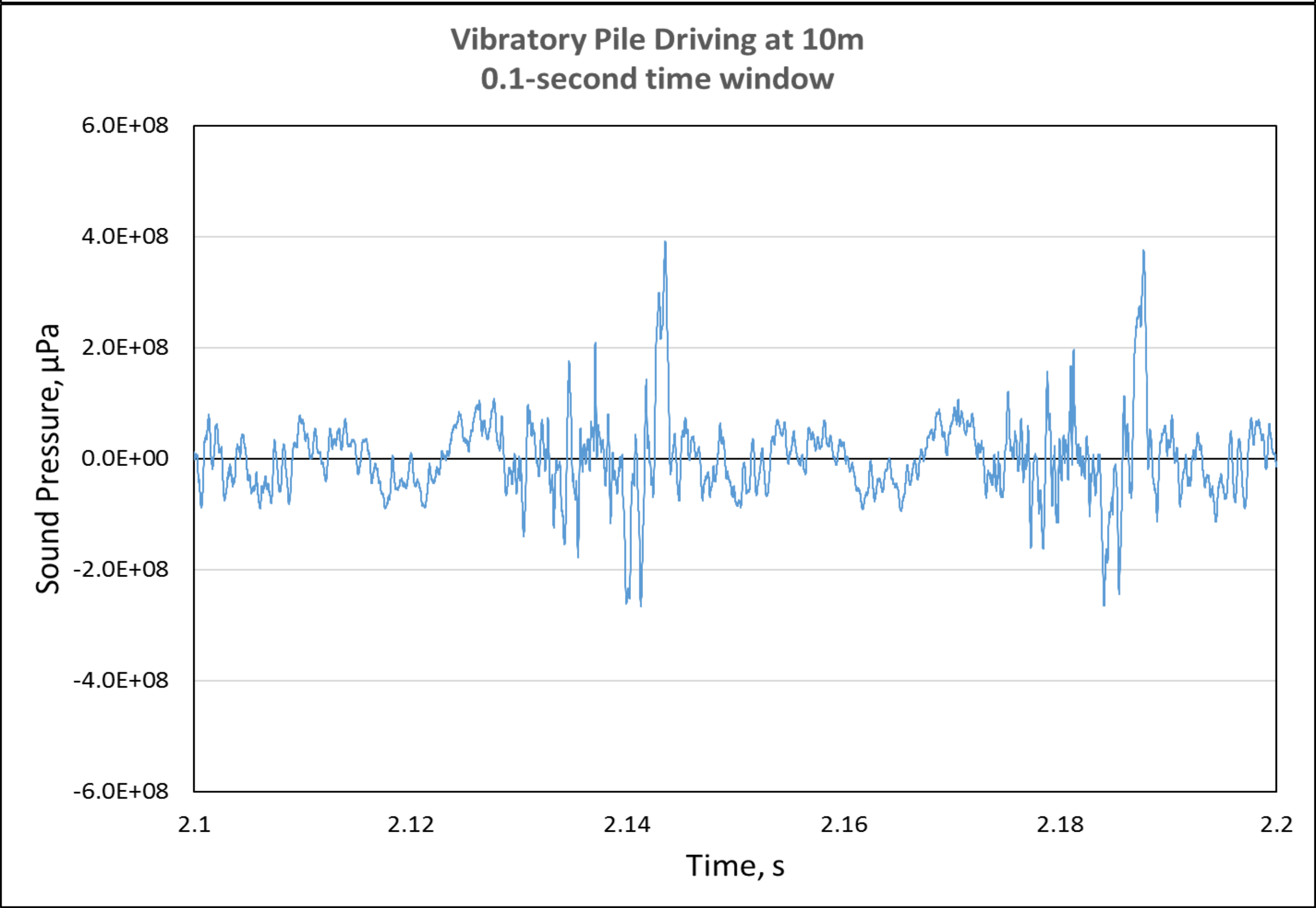


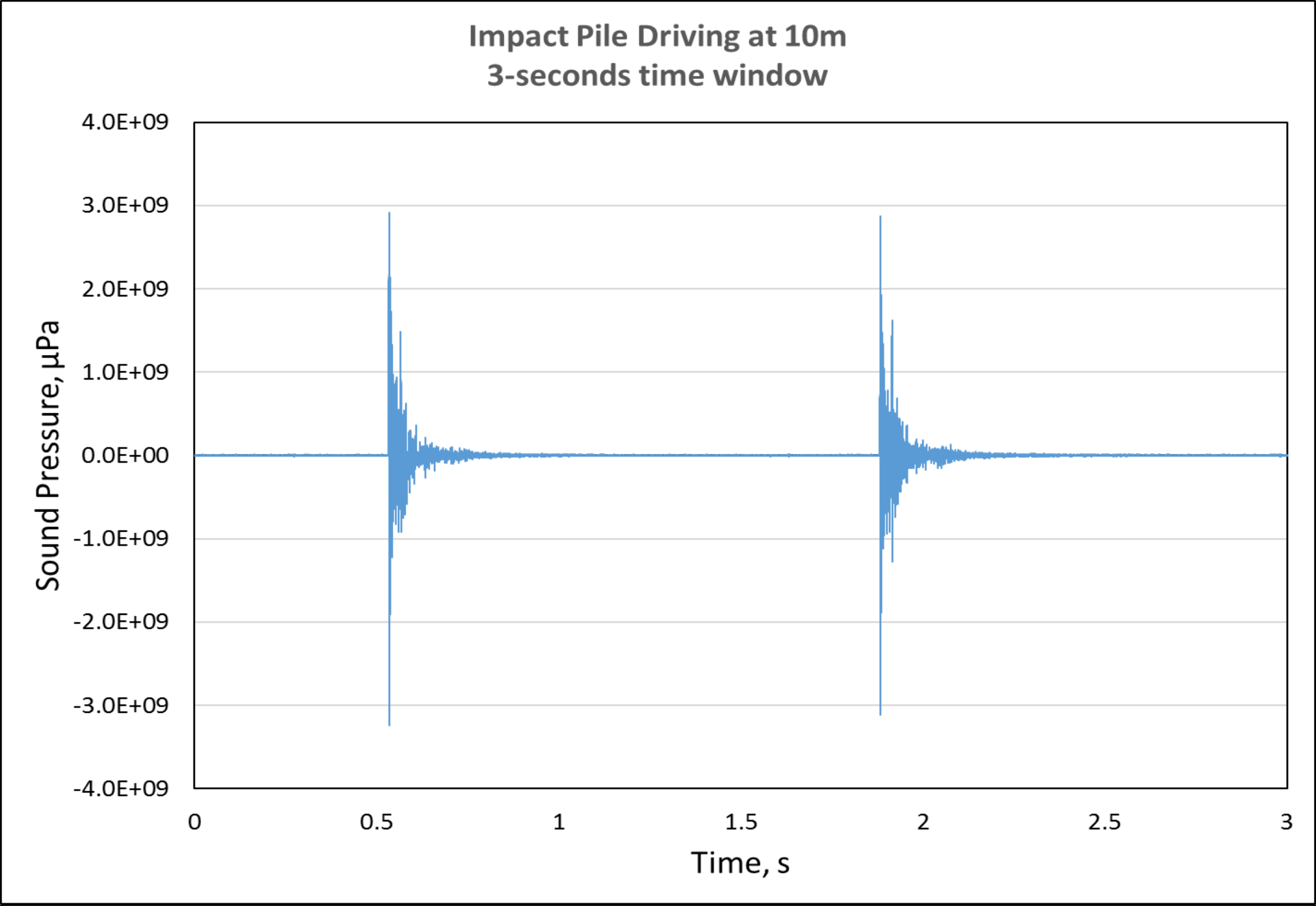
Vibratory Pile Driving at 7km
3-seconds time window
8.0E+06
6.0E+06
4.0E+06
2.0E+06
0.0E+00
-2.0E+06
-4.0E+06
-6.0E+06
-8.0E+06
Sound Pressure, µPa
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
Time, s



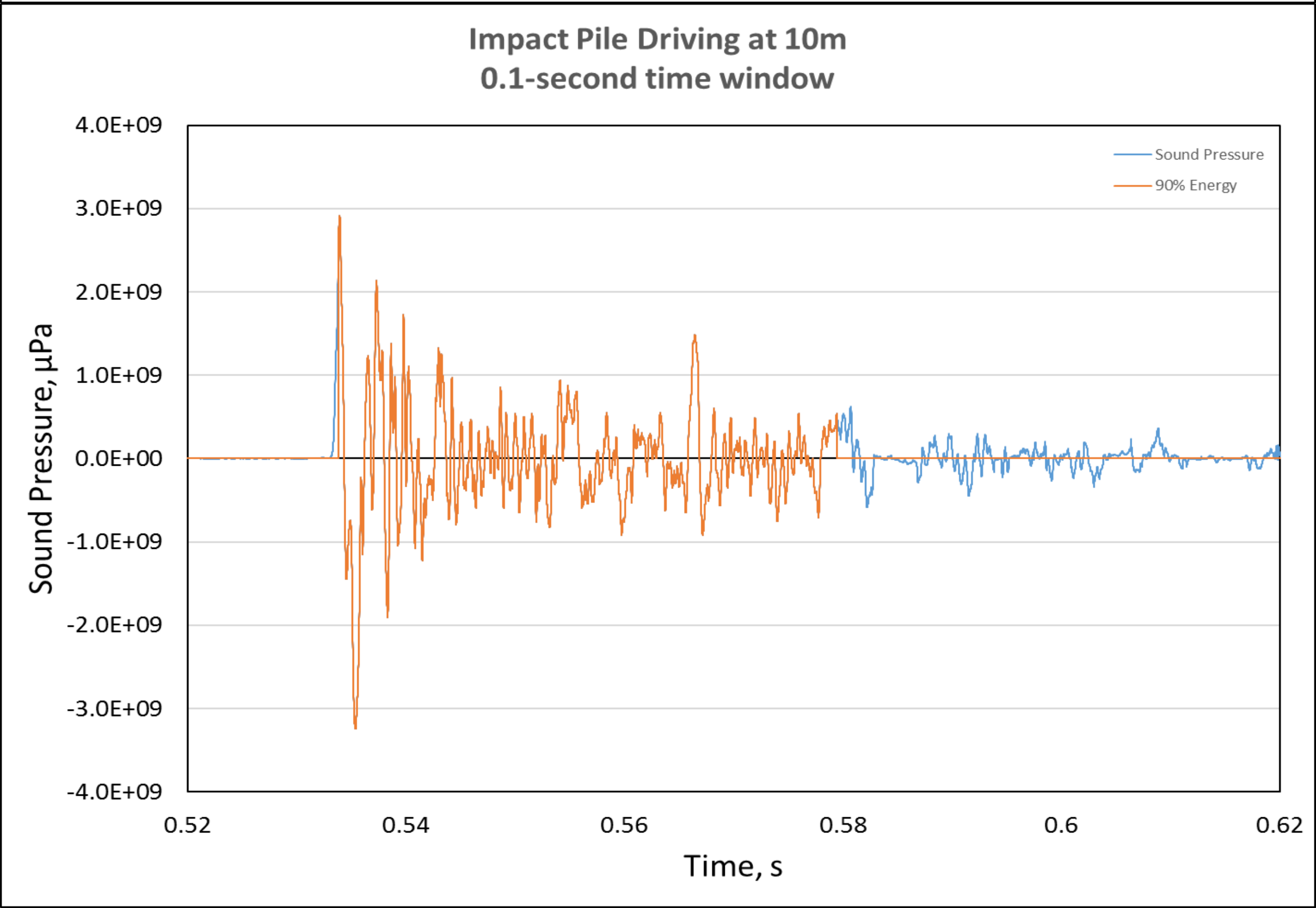
Vibratory Pile Driving at 7km
0.1-second time window
8.0E+06
6.0E+06
4.0E+06
2.0E+06
0.0E+00
-2.0E+06
-4.0E+06
-6.0E+06
-8.0E+06
Sound Pressure, µPa
0.3
0.32
0.34
0.36
0.38
0.4
Time, s


Vibratory Pile Driving at 10m
3-seconds time window
6.0E+08
4.0E+08
2.0E+08
0.0E+00
-2.0E+08
-4.0E+08
-6.0E+08
Sound Pressure, µPa
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
Time, s

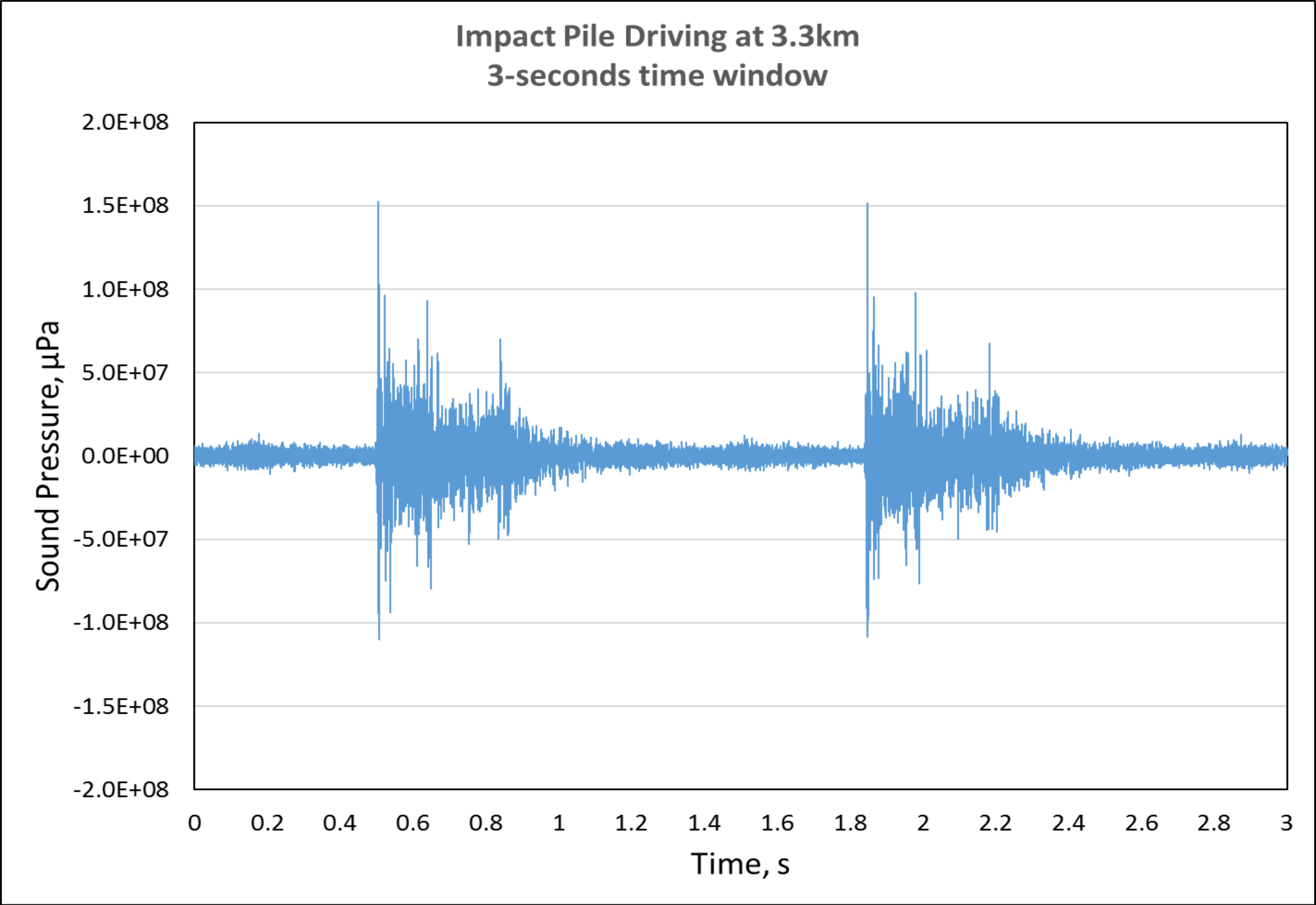

Vibratory Pile Driving at 10m
0.1-second time window
6.0E+08
4.0E+08
2.0E+08
0.0E+00
-2.0E+08
-4.0E+08
-6.0E+08
Sound Pressure, µPa
2.1
2.12
2.14
2.16
2.18
2.2
Time, s



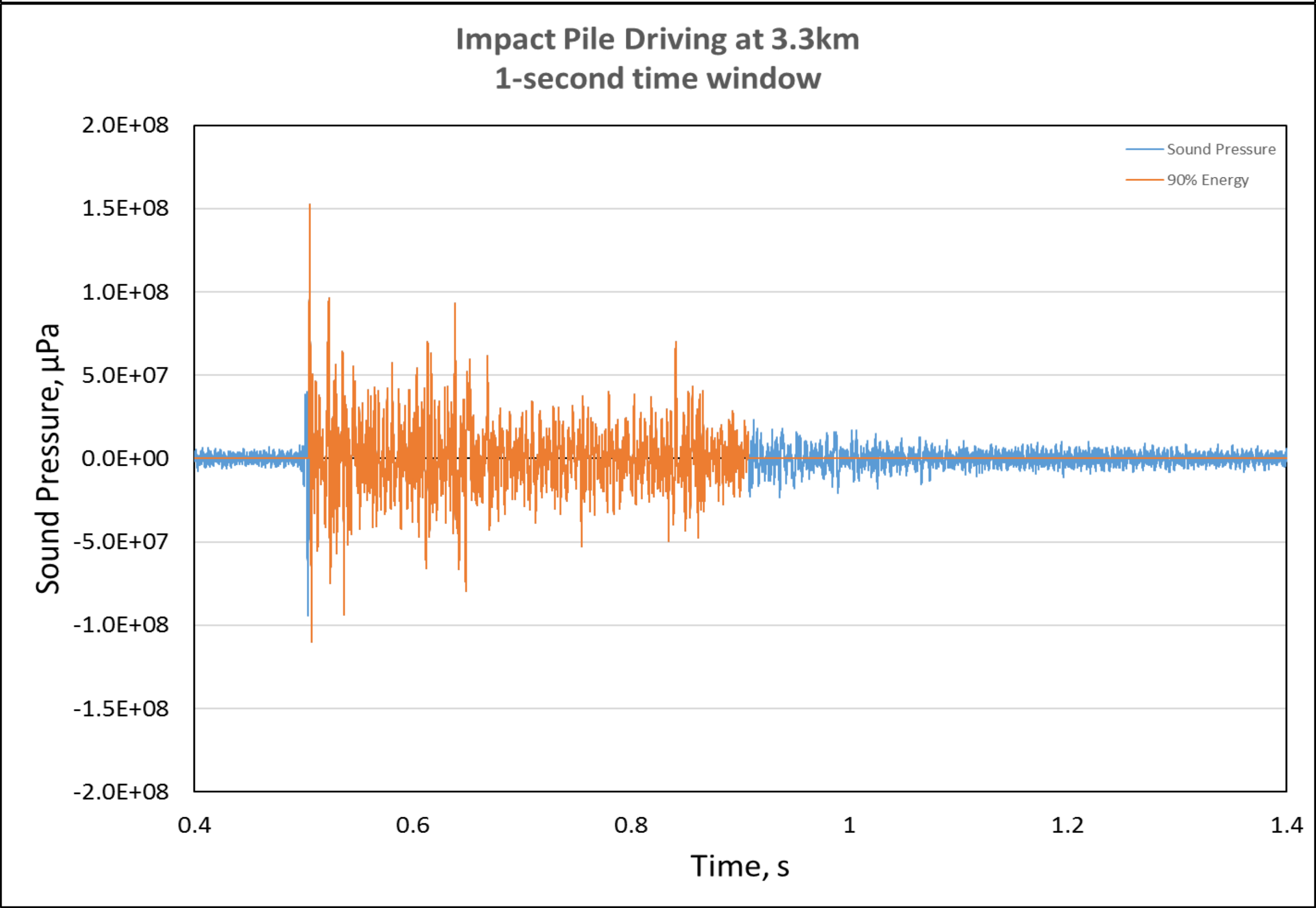
Impact Pile Driving at 10m
3-seconds time window
4.0E+09
3.0E+09
2.0E+09
1.0E+09
0.0E+00
-1.0E+09
-2.0E+09
-3.0E+09
-4.0E+09
Sound Pressure, µPa
0
0.5
1
1.5
2
2.5
3
Time, s



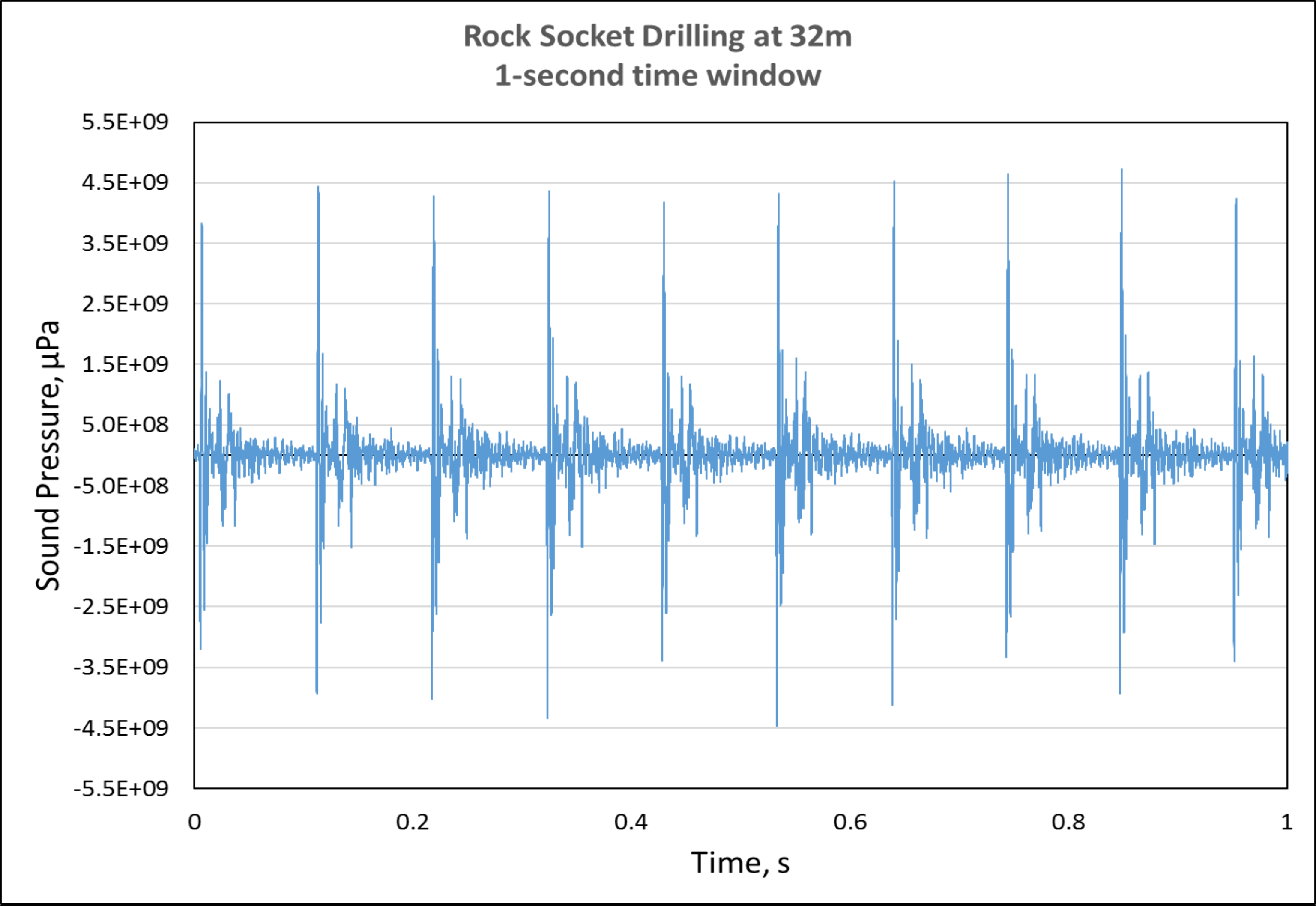
Impact Pile Driving at 10m
0.1-second time window
Sound Pressure
90% Energy
4.0E+09
3.0E+09
2.0E+09
1.0E+09
0.0E+00
-1.0E+09
-2.0E+09
-3.0E+09
-4.0E+09
Sound Pressure, µPa
0.52
0.54
0.56
0.58
0.6
0.62
Time, s

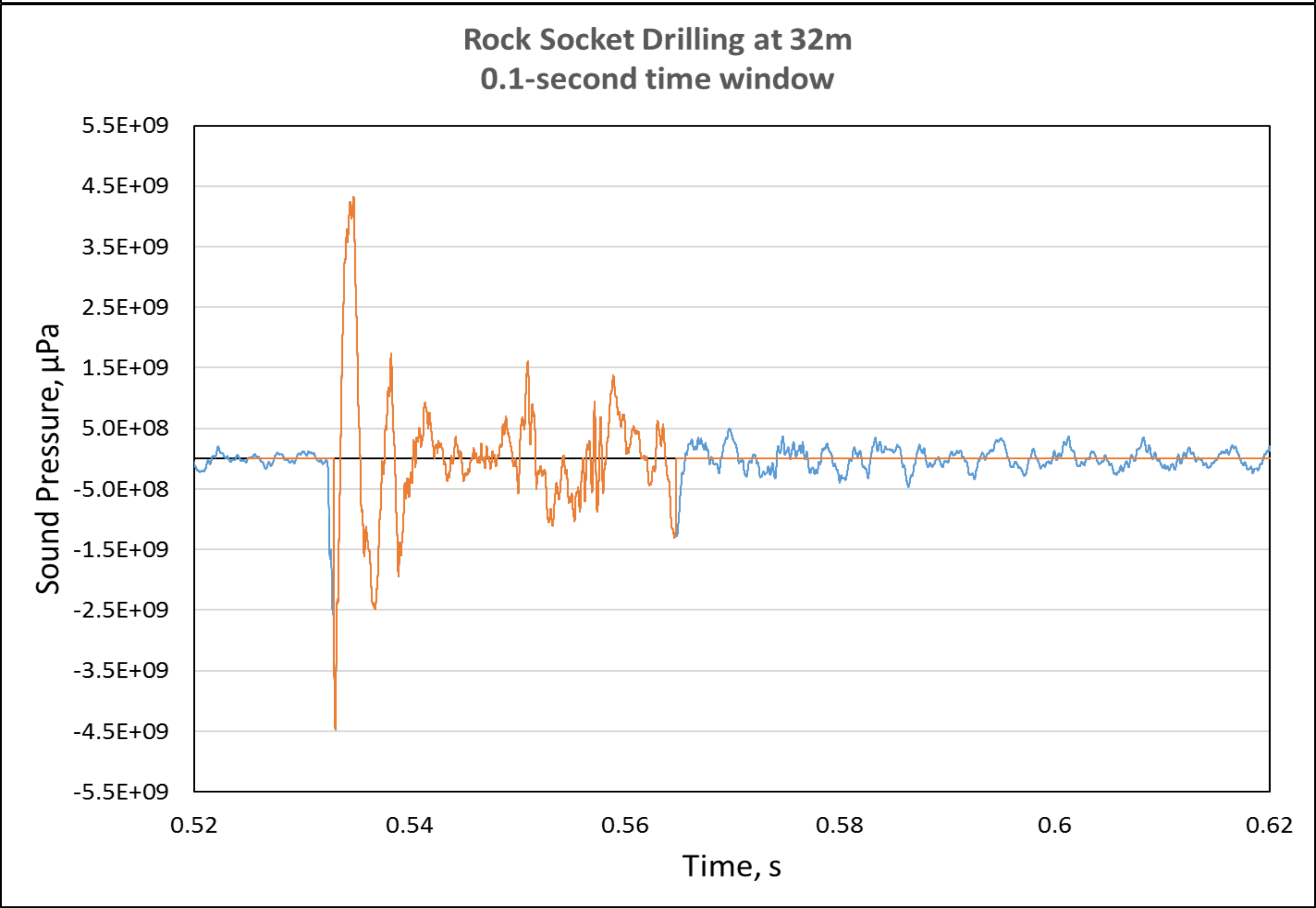


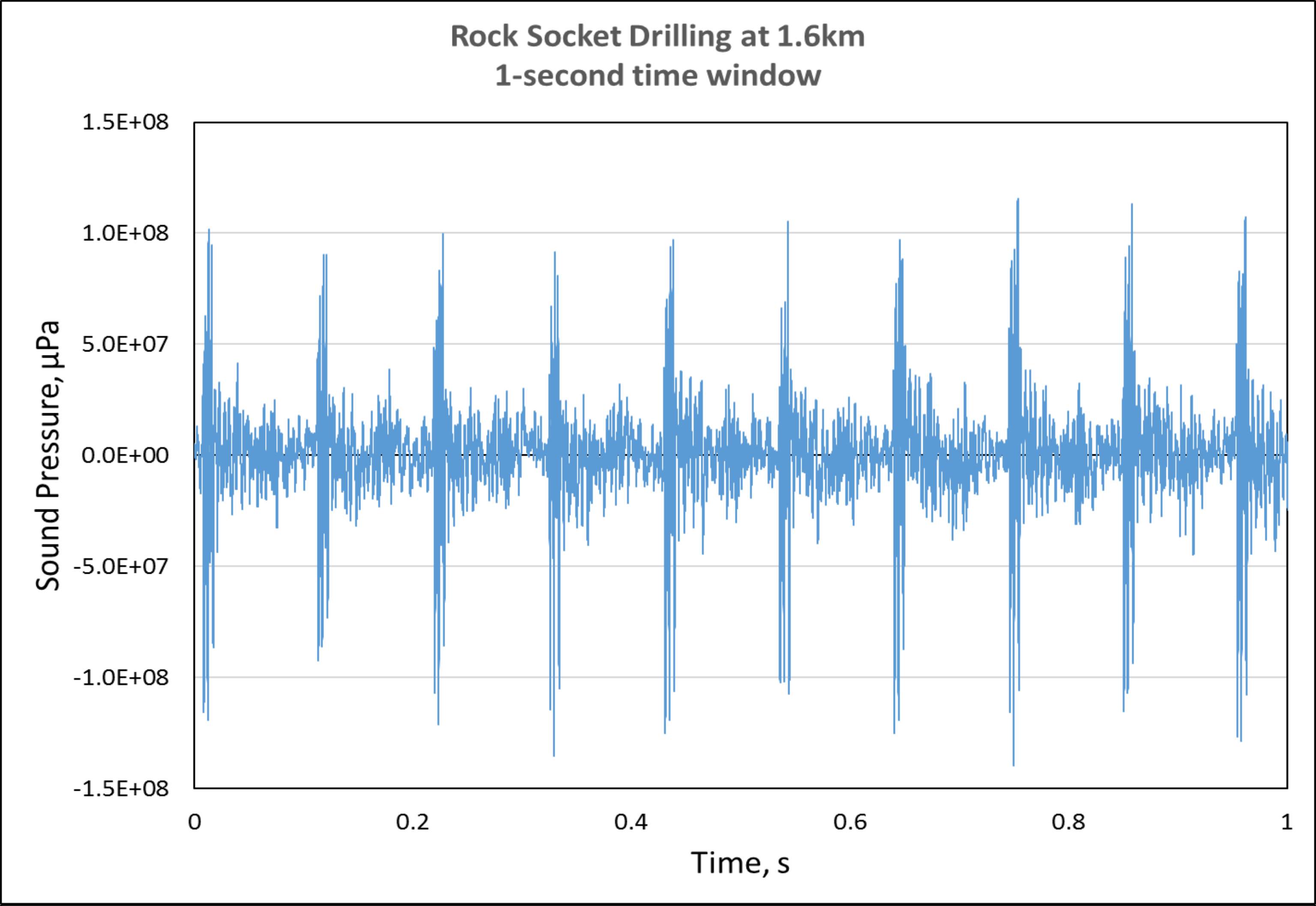
Impact Pile Driving at 3.3km
3-seconds time window
2.0E+08
1.5E+08
1.0E+08
5.0E+07
0.0E+00
-5.0E+07
-1.0E+08
-1.5E+08
-2.0E+08
Sound Pressure, µPa
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
Time, s



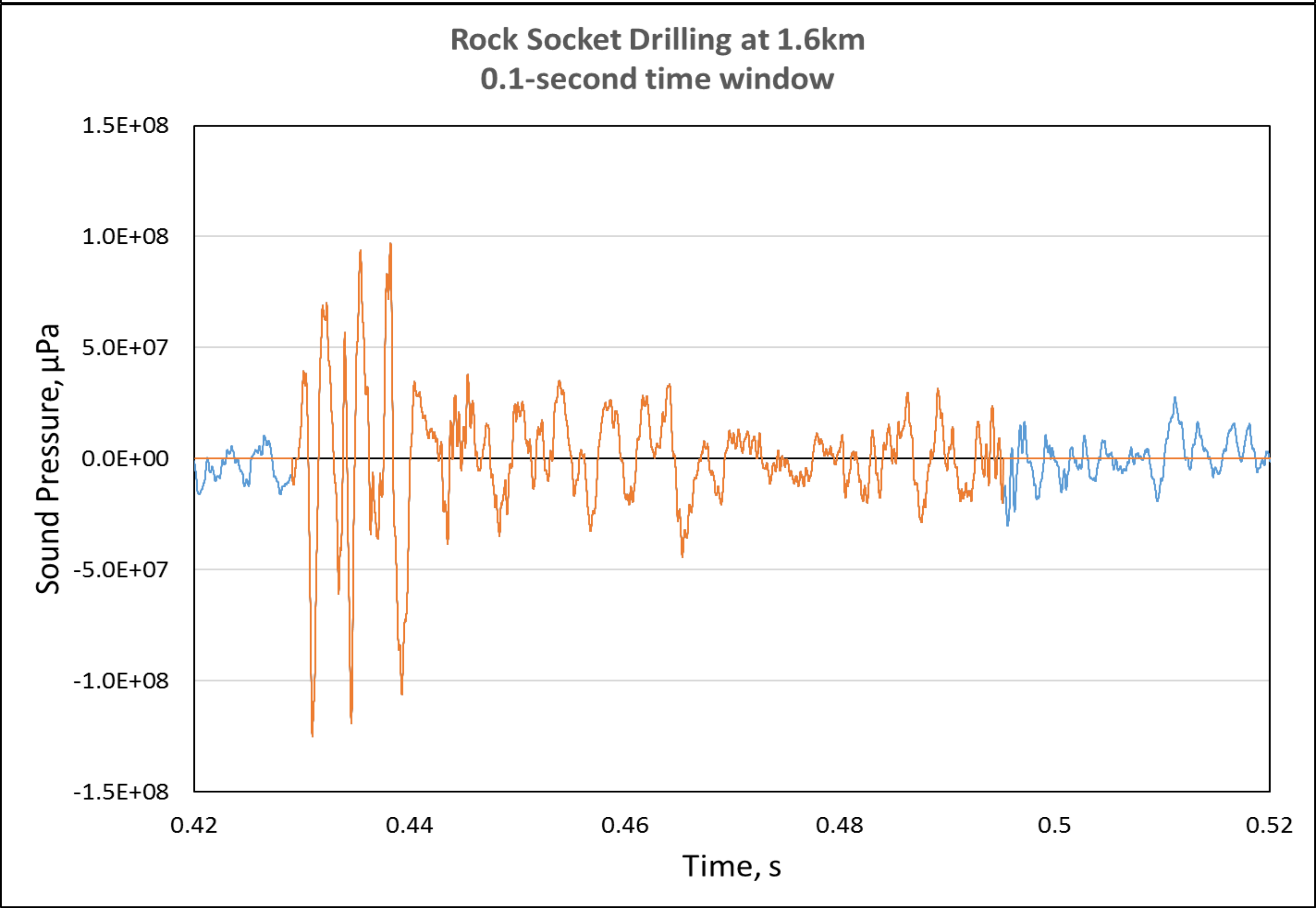
Impact Pile Driving at 3.3km
1-second time window
Sound Pressure
90% Energy
2.0E+08
1.5E+08
1.0E+08
5.0E+07
0.0E+00
-5.0E+07
-1.0E+08
-1.5E+08
-2.0E+08
Sound Pressure, µPa
0.4
0.6
0.8
1
1.2
1.4
Time, s


Rock Socket Drilling at 32m
1-second time window
Sound Pressure, µPa
5.5E+09
4.5E+09
3.5E+09
2.5E+09
1.5E+09
5.0E+08
-5.0E+08
-1.5E+09
-2.5E+09
-3.5E+09
-4.5E+09
-5.5E+09
0
0.2
0.4
0.6
0.8
1
Time, s

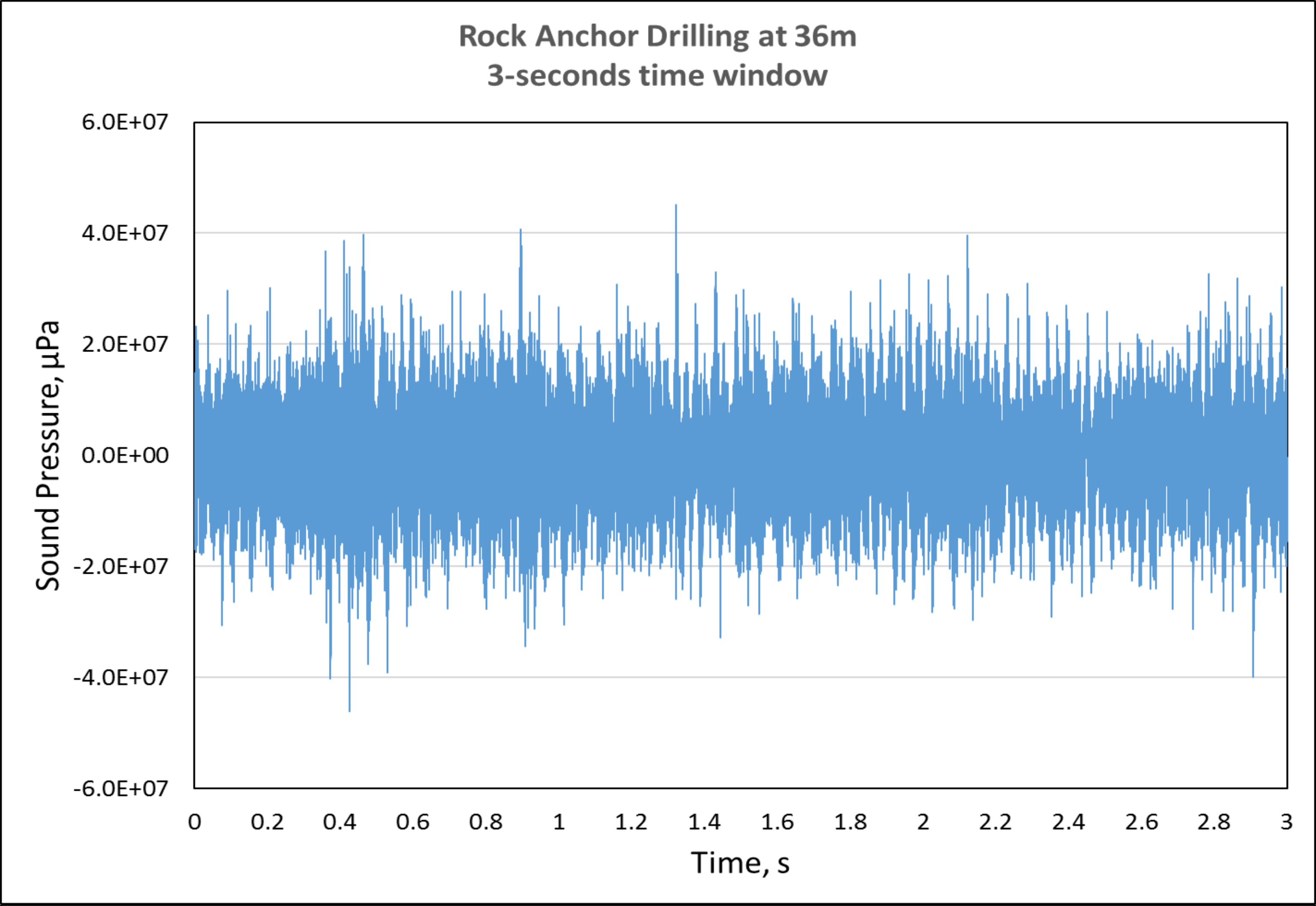

Rock Socket Drilling at 32m
0.1-second time window
Sound Pressure, µPa
5.5E+09
4.5E+09
3.5E+09
2.5E+09
1.5E+09
5.0E+08
-5.0E+08
-1.5E+09
-2.5E+09
-3.5E+09
-4.5E+09
-5.5E+09
0.52
0.54
0.56
0.58
0.6
0.62
Time, s

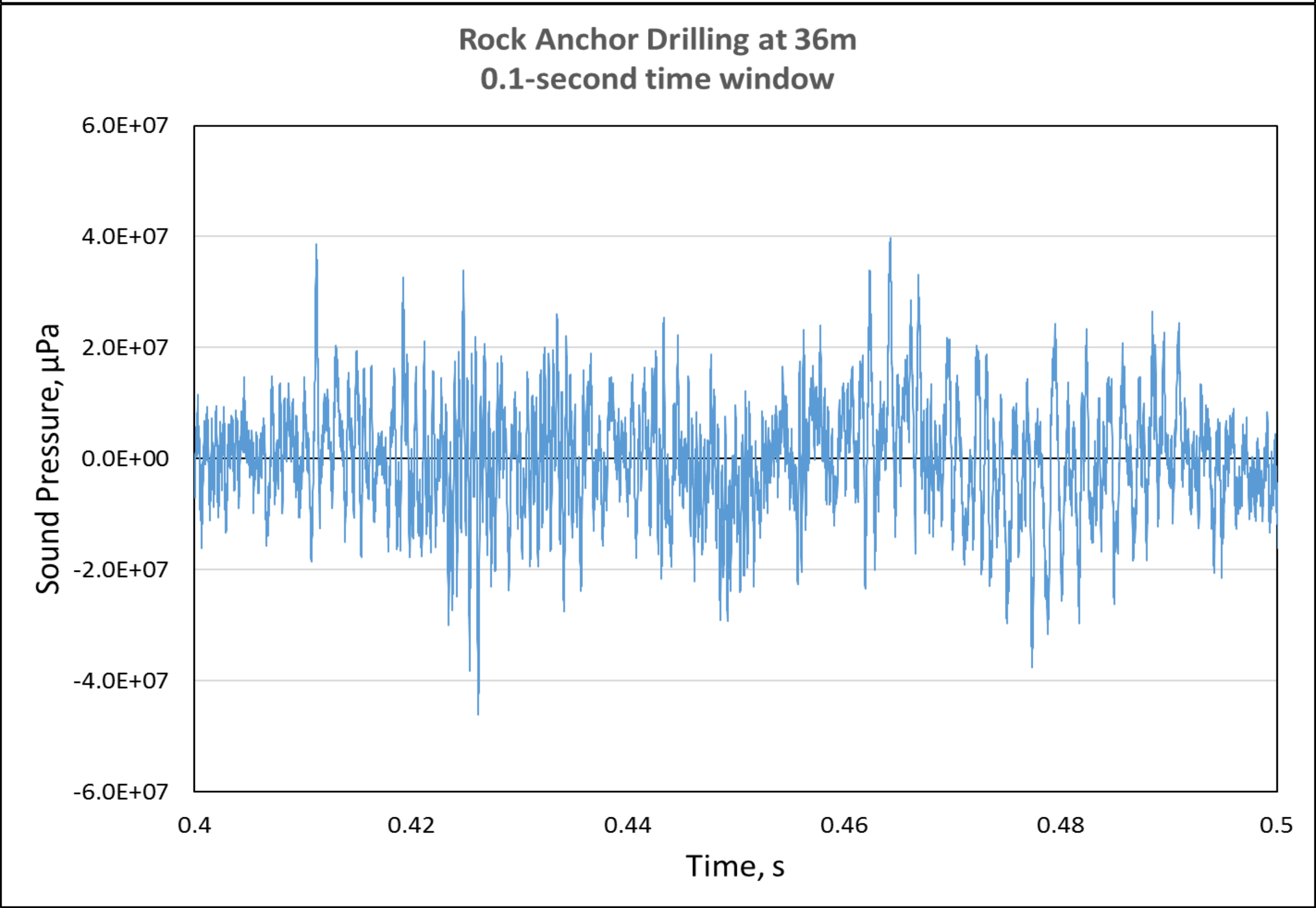


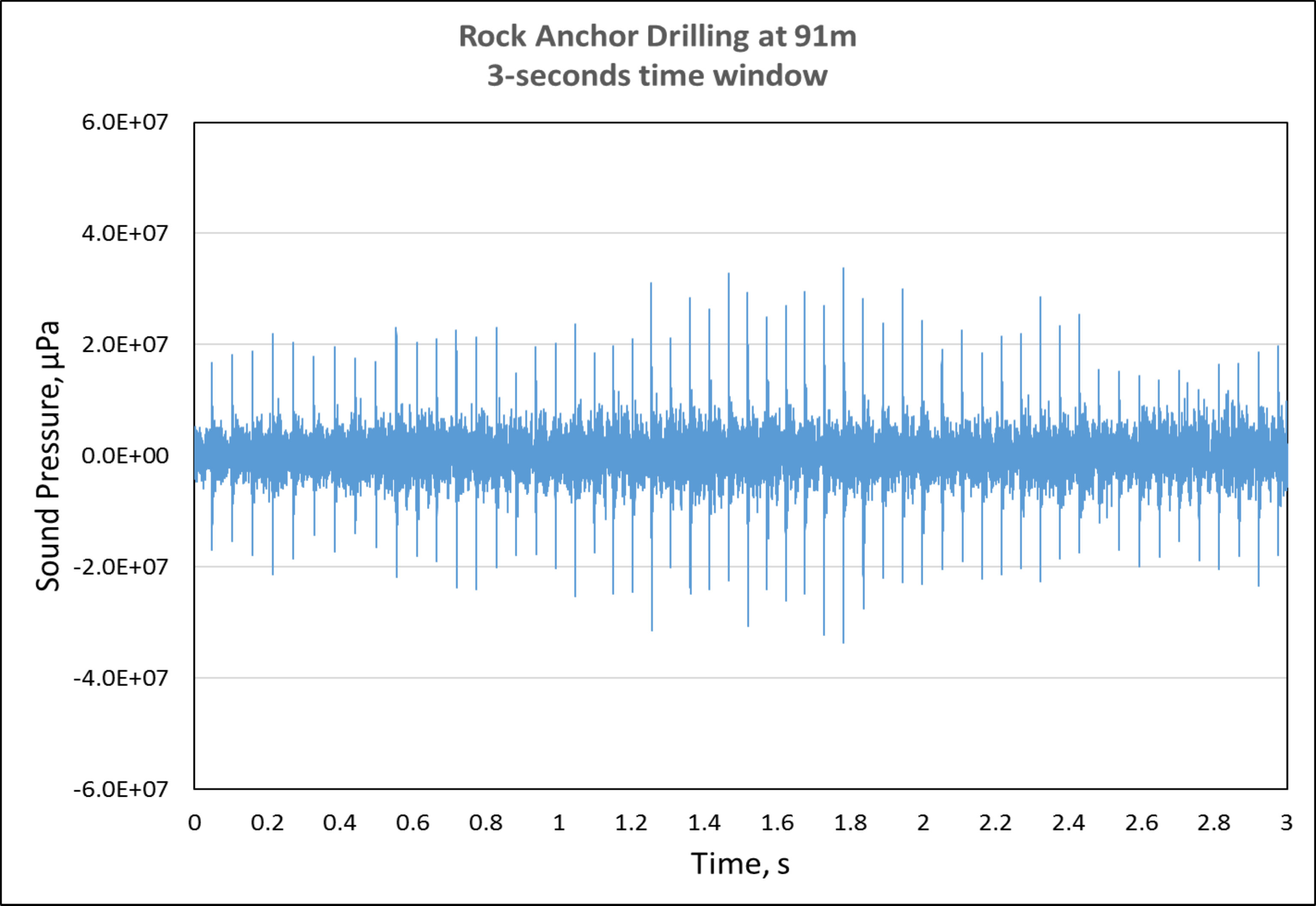
Rock Socket Drilling at 1.6km
1-second time window
Sound Pressure, µPa
1.5E+08
1.0E+08
5.0E+07
0.0E+00
-5.0E+07
-1.0E+08
-1.5E+08
0
0.2
0.4
0.6
0.8
1
Time, s

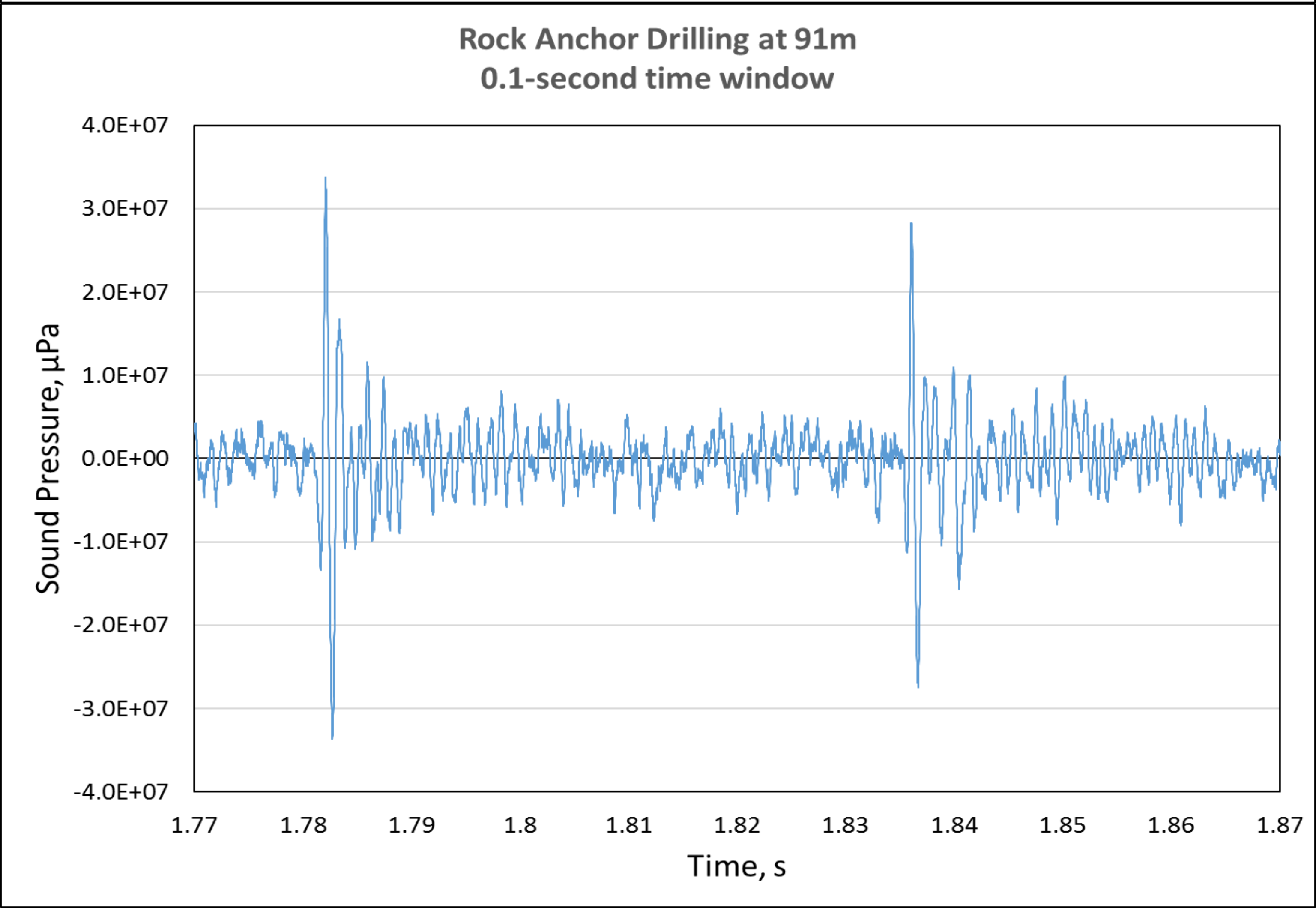


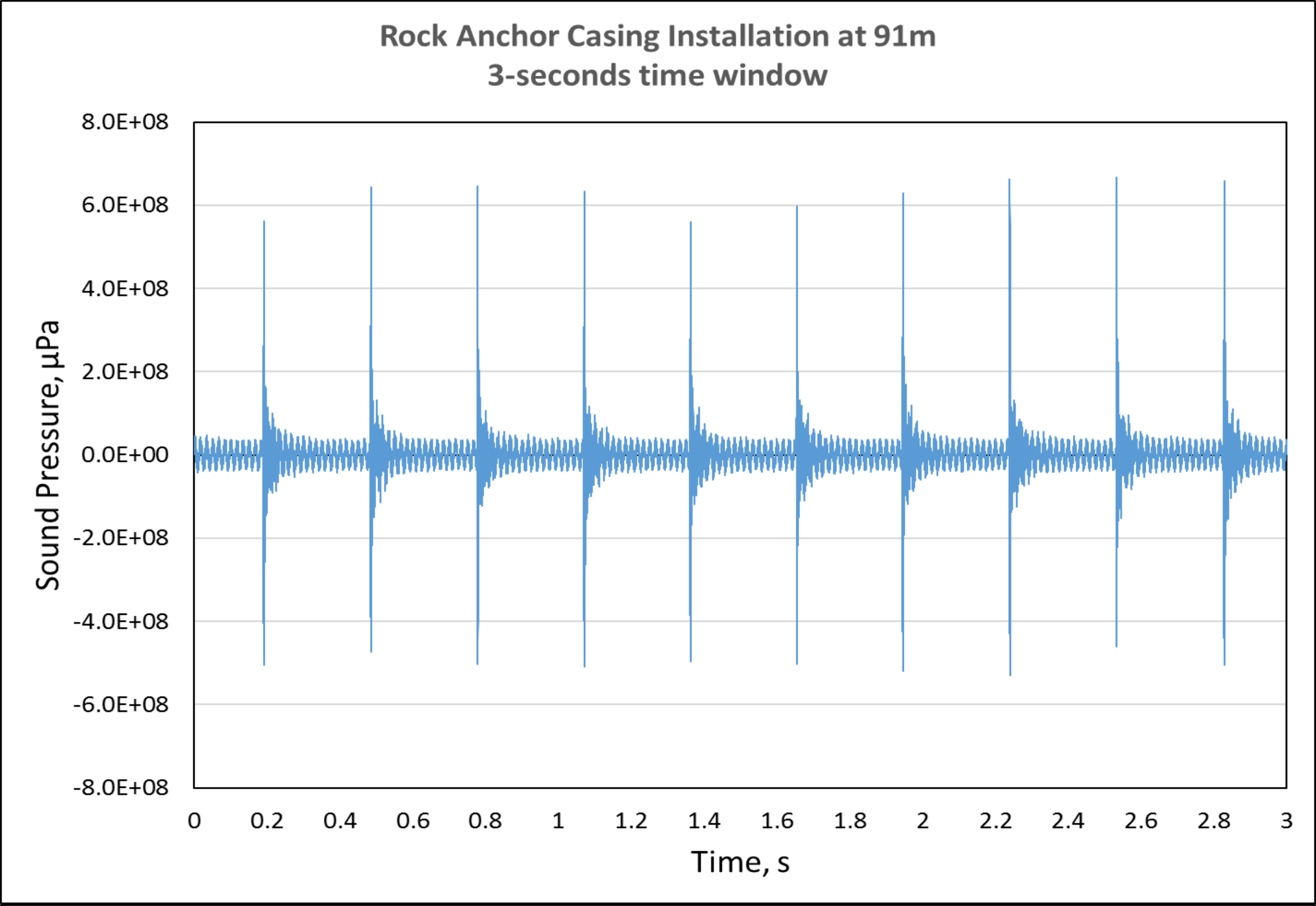
Rock Socket Drilling at 1.6km
0.1-second time window
Sound Pressure, µPa
1.5E+08
1.0E+08
5.0E+07
0.0E+00
-5.0E+07
-1.0E+08
-1.5E+08
0.42
0.44
0.46
0.48
0.5
0.52
Time, s

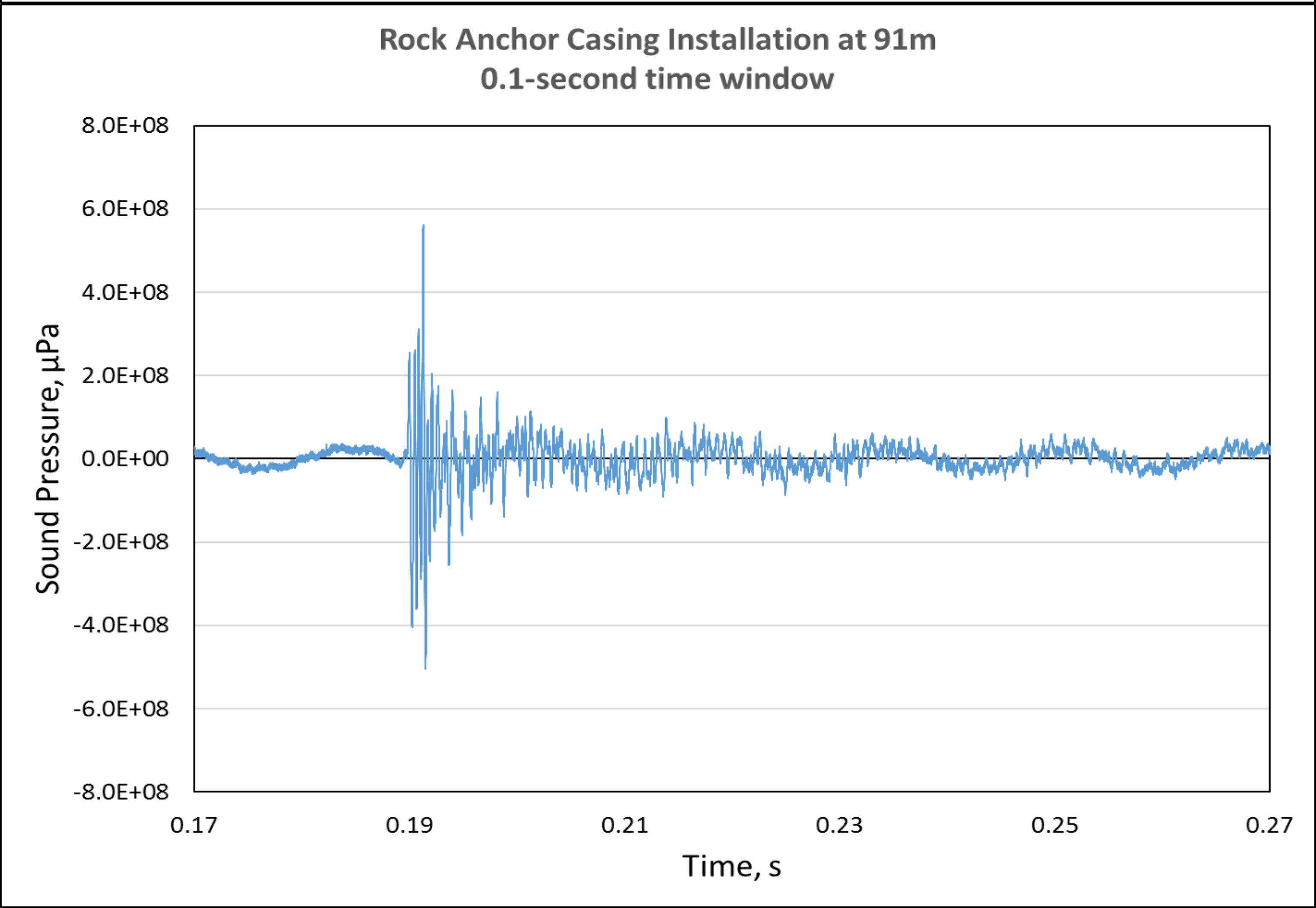

Rock Anchor Drilling at 36m
3-seconds time window
6.0E+07
4.0E+07
2.0E+07
0.0E+00
-2.0E+07
-4.0E+07
-6.0E+07
Sound Pressure, µPa
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
Time, s


Rock Anchor Drilling at 36m
0.1-second time window
6.0E+07
4.0E+07
2.0E+07
0.0E+00
-2.0E+07
-4.0E+07
-6.0E+07
Sound Pressure, µPa
0.4
0.42
0.44
0.46
0.48
0.5
Time, s


Rock Anchor Drilling at 91m
3-seconds time window
6.0E+07
4.0E+07
2.0E+07
0.0E+00
-2.0E+07
-4.0E+07
-6.0E+07
Sound Pressure, μPa
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
Time, s


Rock Anchor Drilling at 91m
0.1-second time window
4.0E+07
3.0E+07
2.0E+07
1.0E+07
0.0E+00
-1.0E+07
-2.0E+07
-3.0E+07
-4.0E+07
Sound Pressure, μPa
1.77
1.78
1.79
1.8
1.81
1.82
1.83
1.84
1.85
1.86
1.87
Time, s

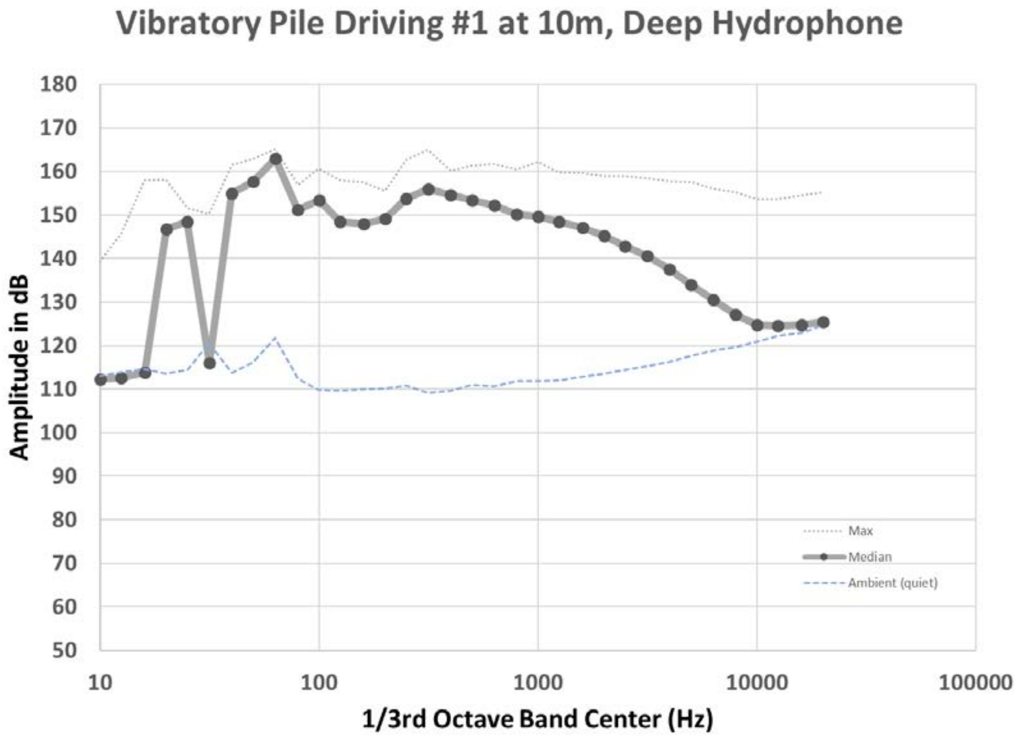

Rock Anchor Casing Installation at 91m
3-seconds time window
Sound Pressure, µPa
Time, s
8.0E+08
6.0E+08
4.0E+08
2.0E+08
0.0E+00
-2.0E+08
-4.0E+08
-6.0E+08
-8.0E+08
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3

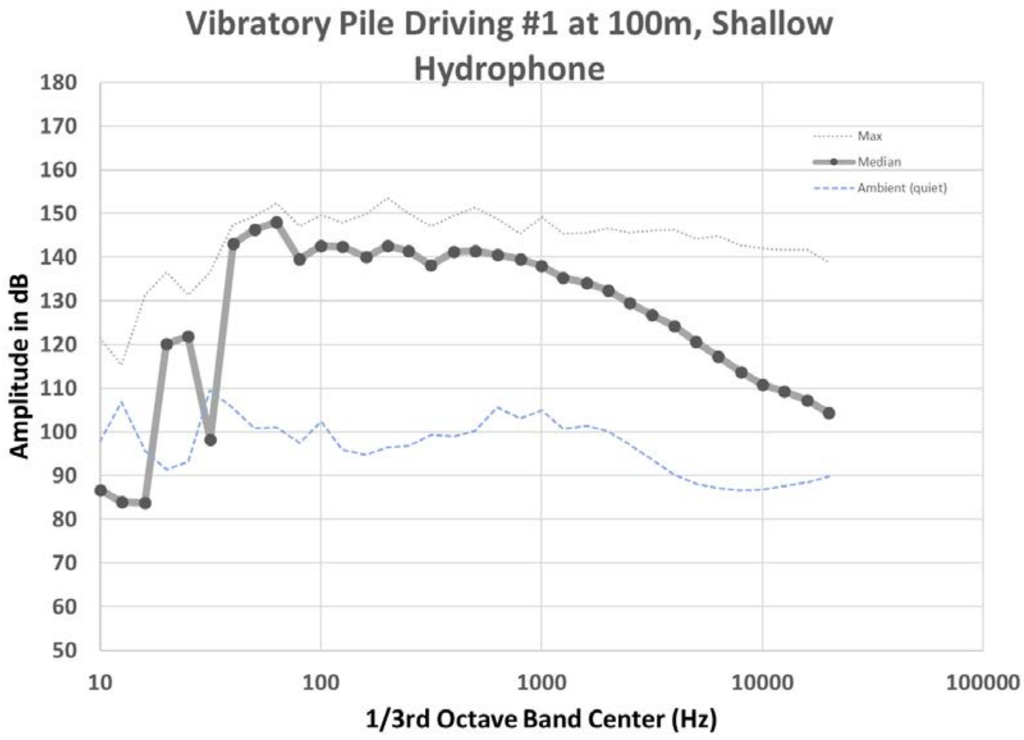

Rock Anchor Casing Installation at 91m
0.1-second time window
Sound Pressure, µPa
Time, s
8.0E+08
6.0E+08
4.0E+08
2.0E+08
0.0E+00
-2.0E+08
-4.0E+08
-6.0E+08
-8.0E+08
0.17 0.19 0.21 0.23 0.25 0.27

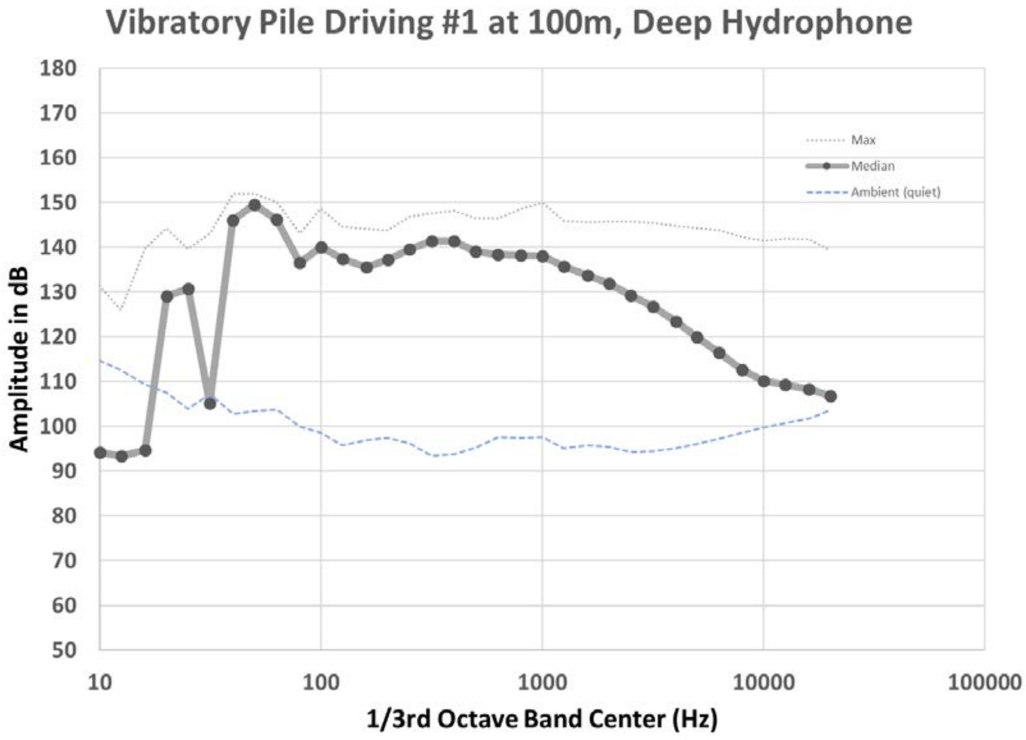
Appendix E – 1/3rd Octave Band and Power Spectrum Density Distributions

Vibratory Pile Driving #1 at 10m, Shallow Hydrophone

N/A

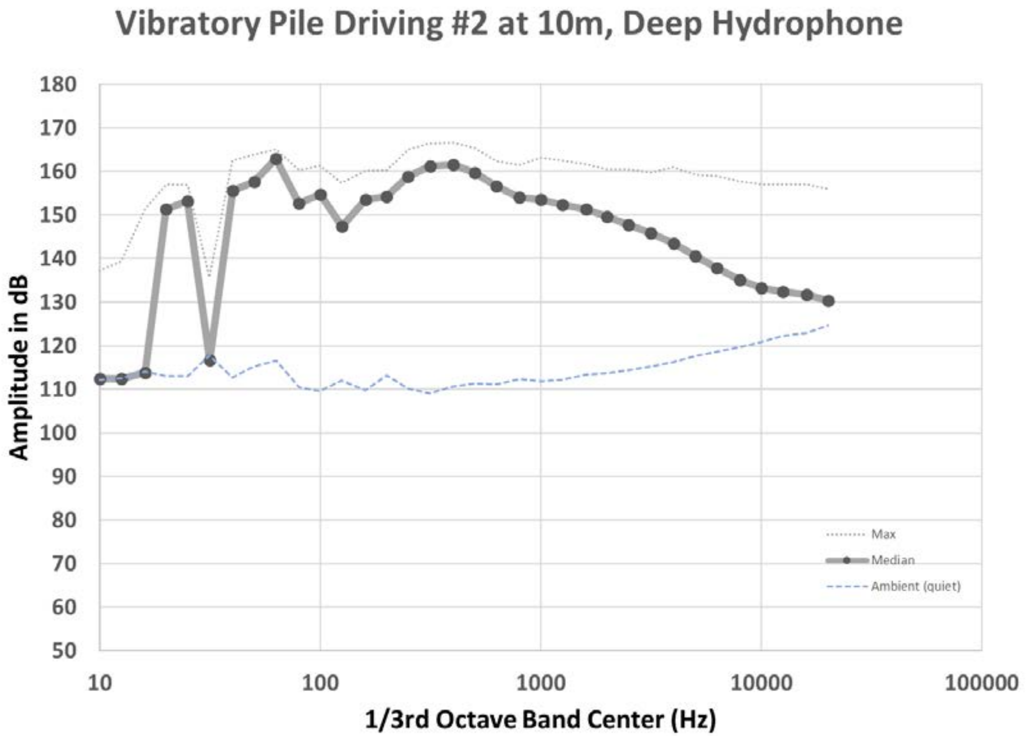


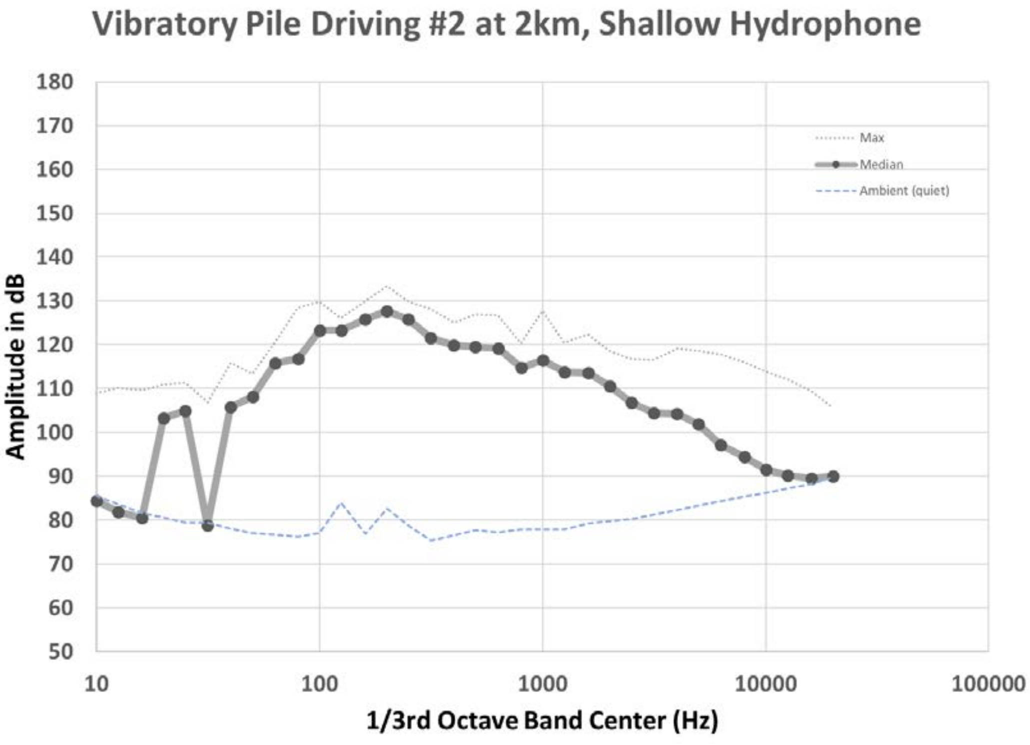


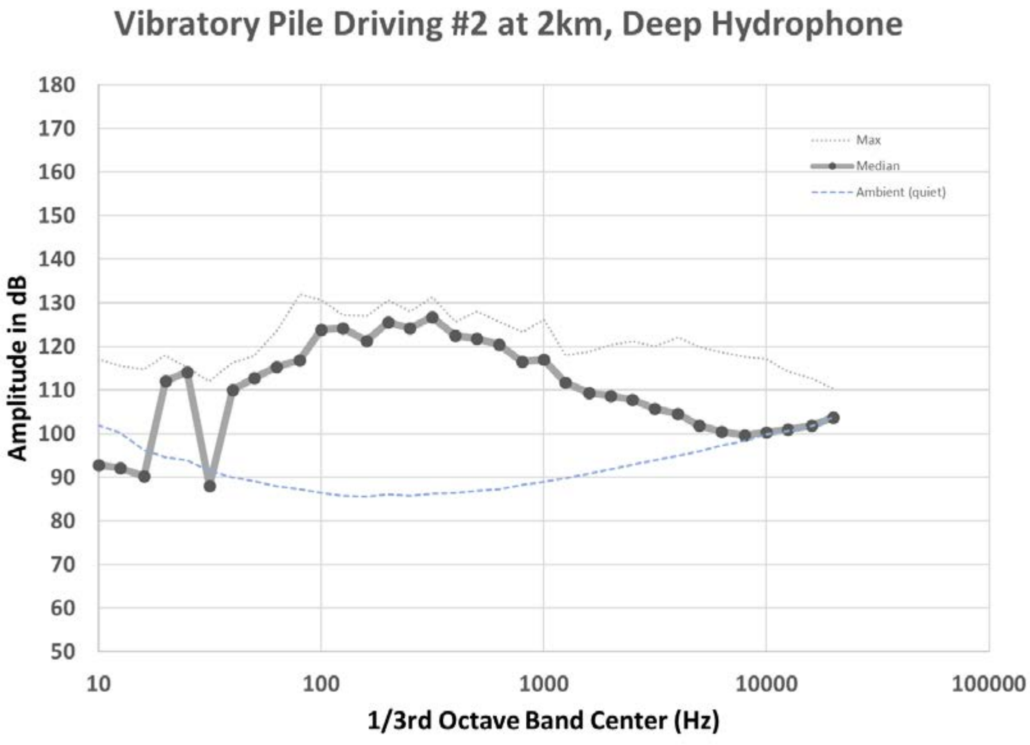


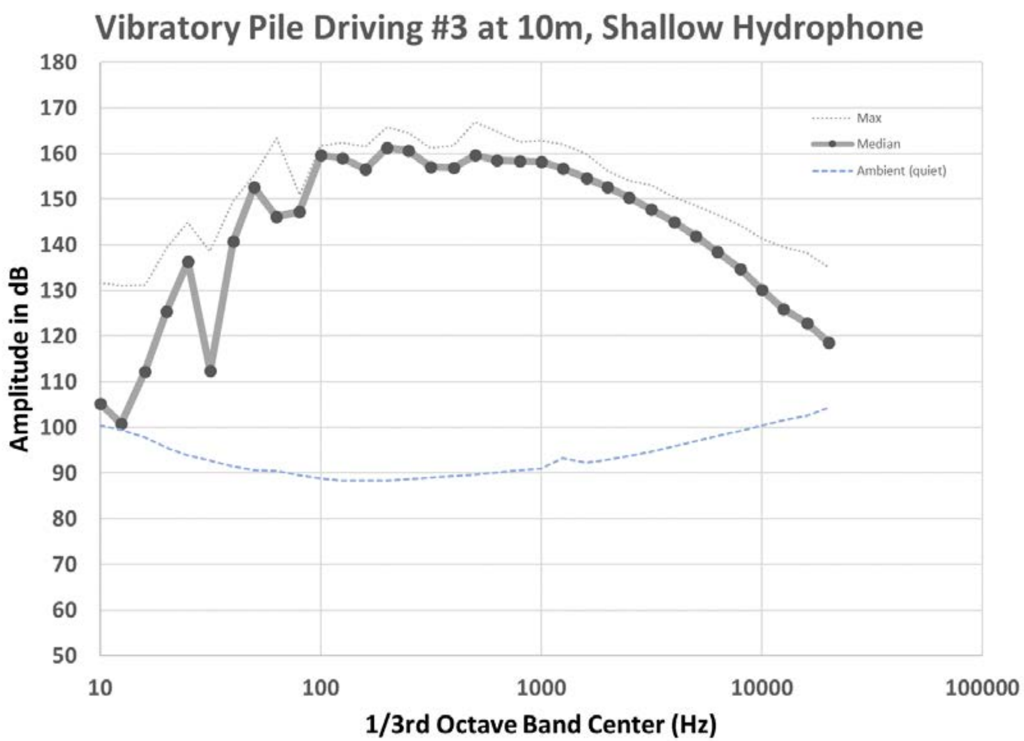
Vibratory Pile Driving #2
at 10m, Shallow
Hydrophone

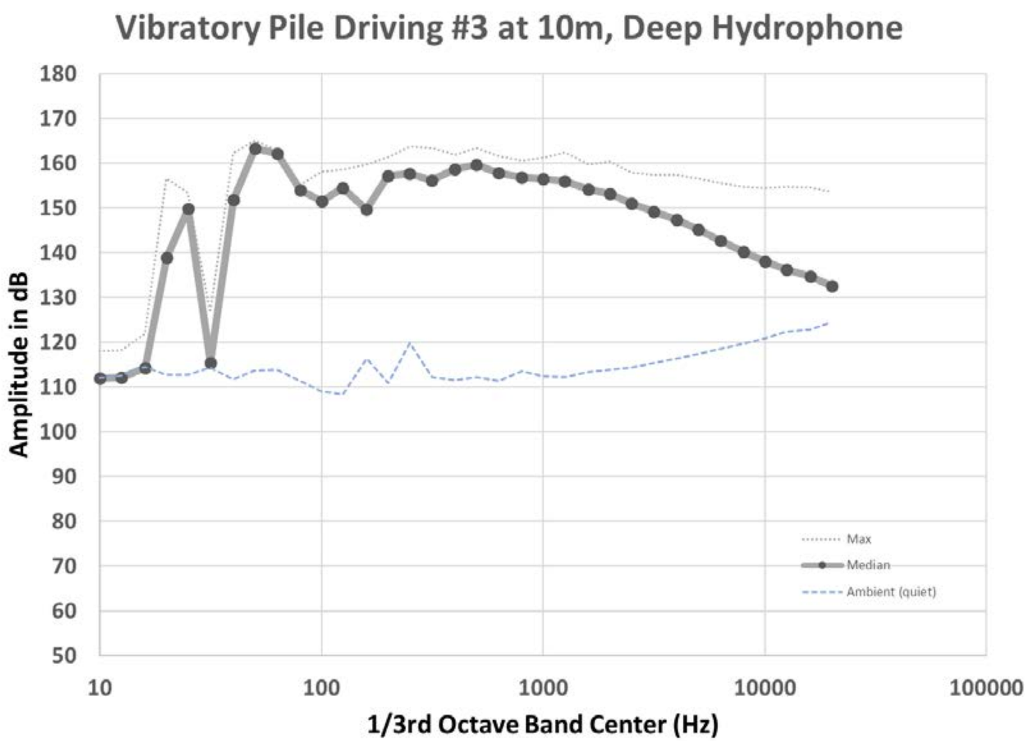
N/A

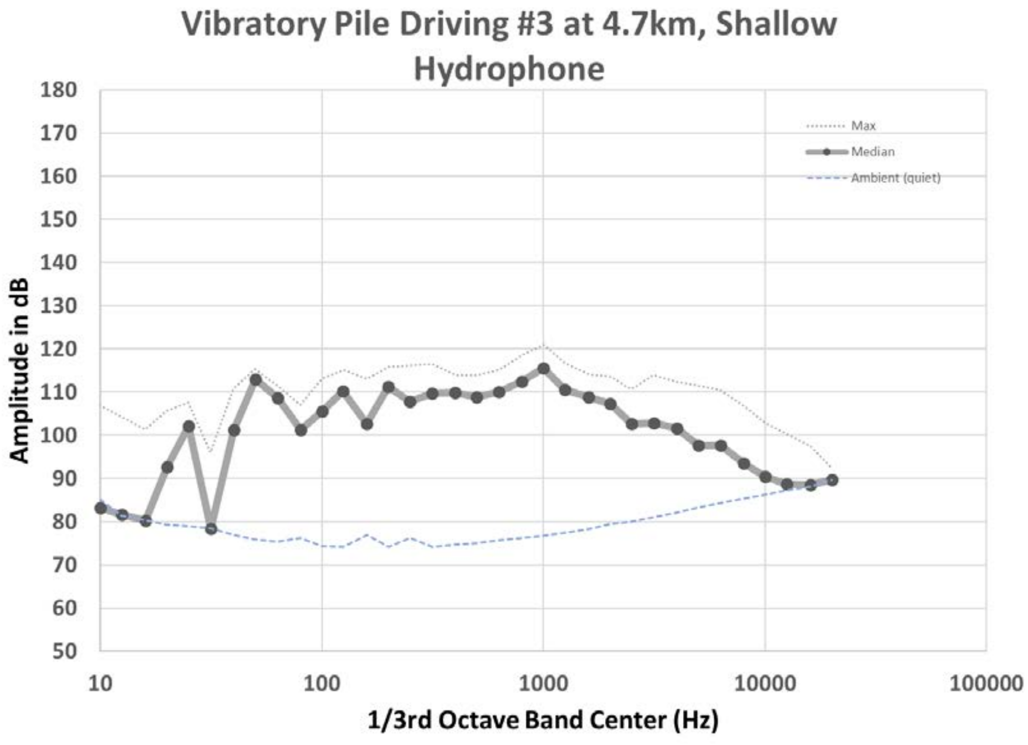


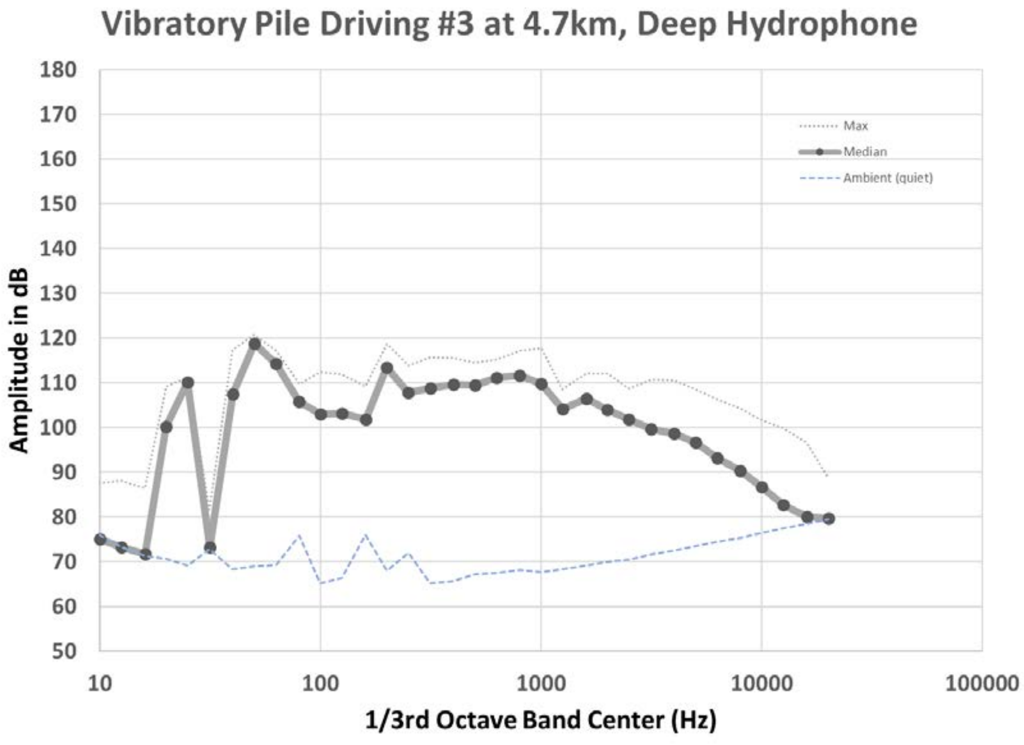


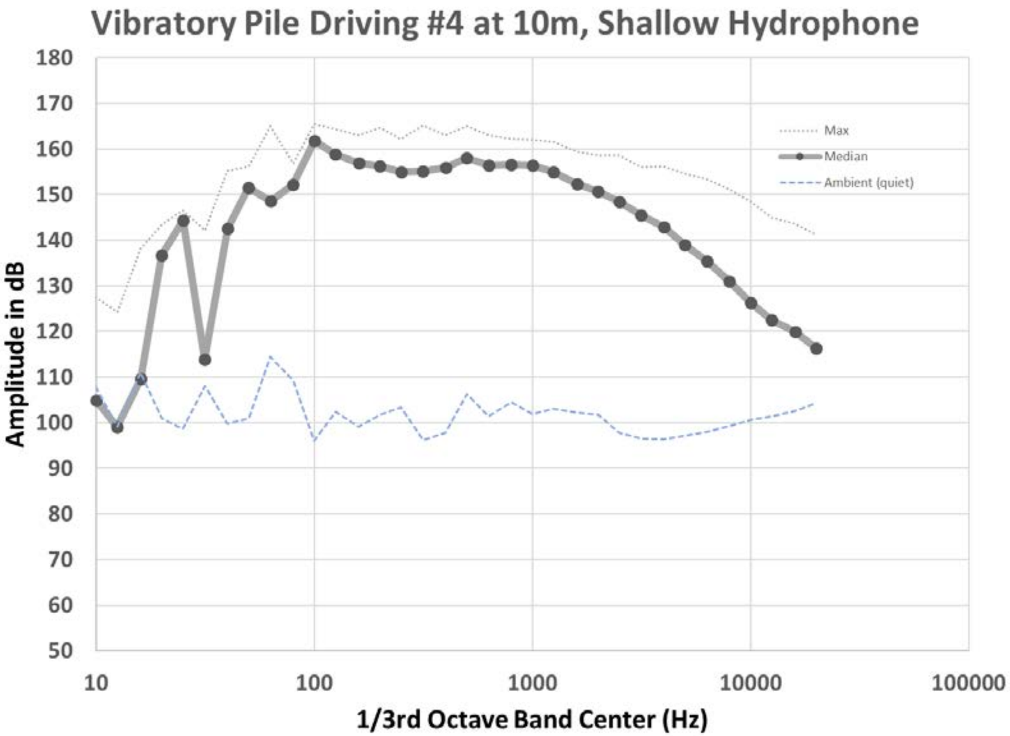


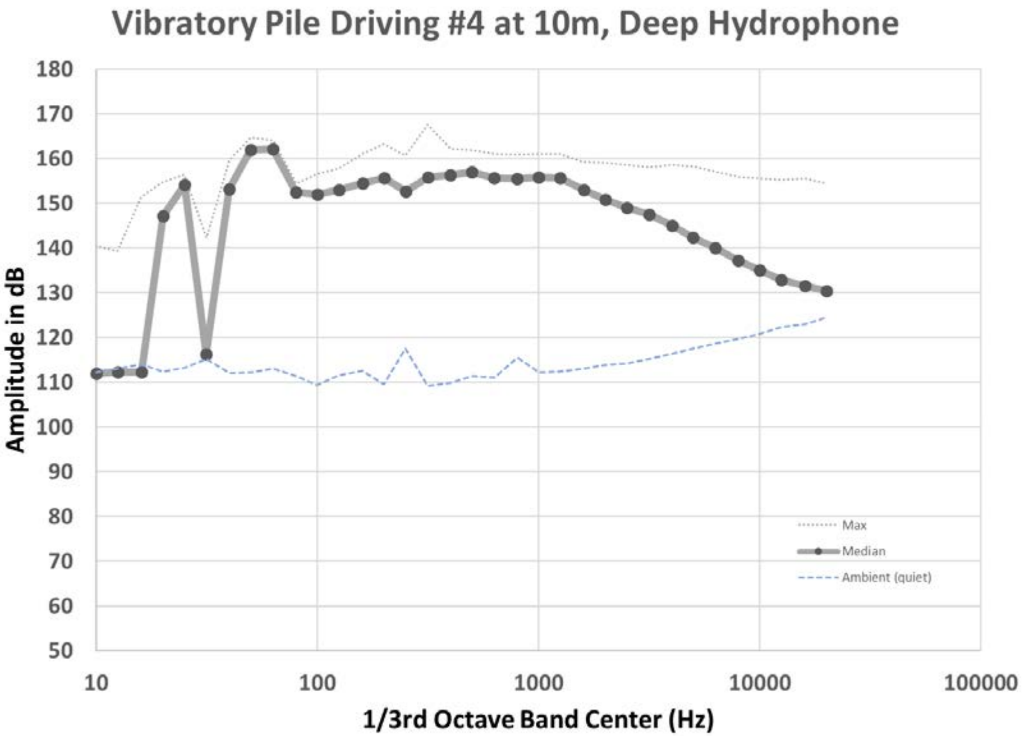

Vibratory Pile Driving #3 at 10m, Shallow Hydrophone
Amplitude in dB
1/3rd Octave Band Center (Hz)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
10
100
1000
10000
100000
Max
Median
Ambient (quiet)

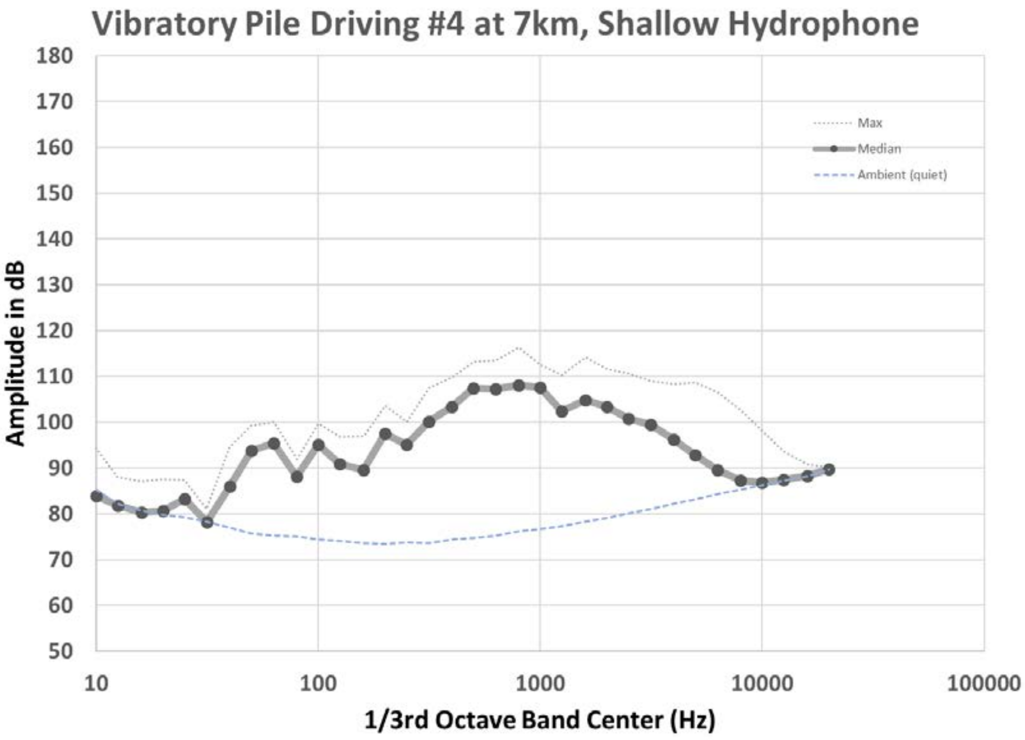

Vibratory Pile Driving #3 at 10m, Deep Hydrophone
Amplitude in dB
1/3rd Octave Band Center (Hz)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
10
100
1000
10000
100000
Max
Median
Ambient (quiet)

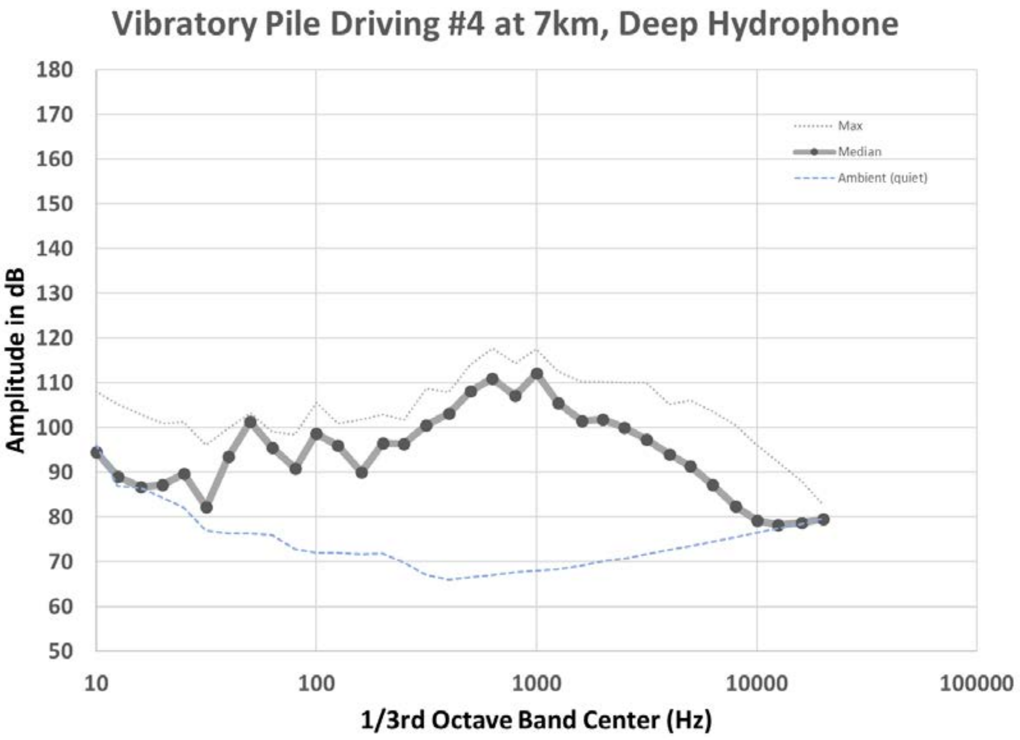

Vibratory Pile Driving #3 at 4.7km, Shallow Hydrophone
Amplitude in dB
1/3rd Octave Band Center (Hz)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
10
100
1000
10000
100000
Max
Median
Ambient (quiet)

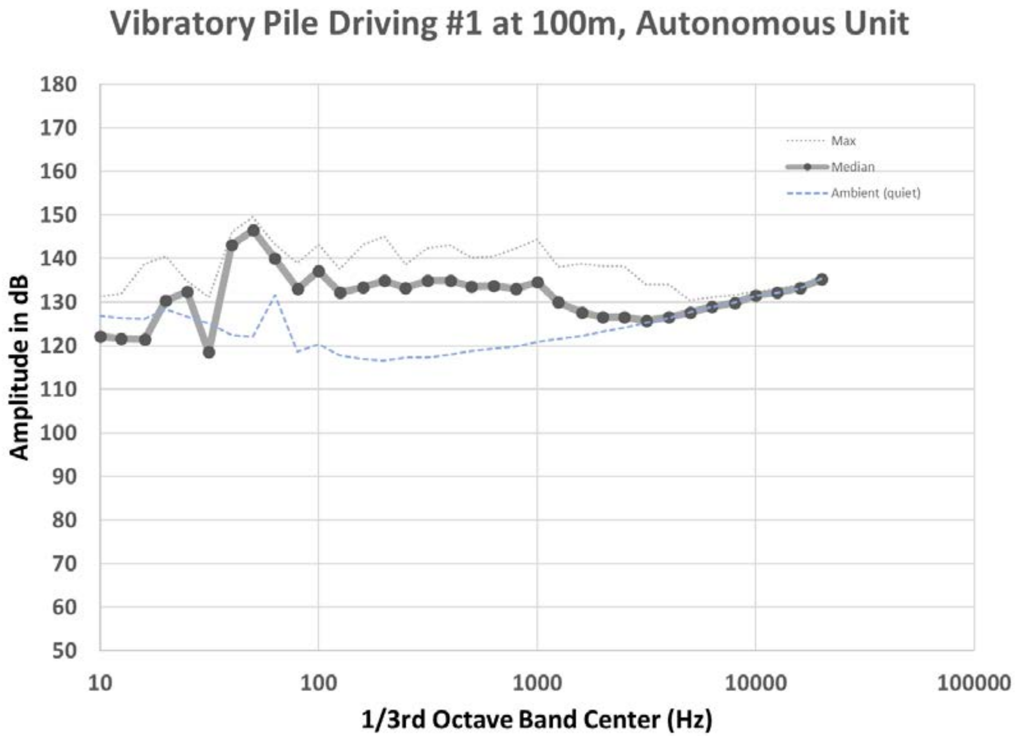

Vibratory Pile Driving #3 at 4.7km, Deep Hydrophone
Amplitude in dB
1/3rd Octave Band Center (Hz)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
10
100
1000
10000
100000
Max
Median
Ambient (quiet)

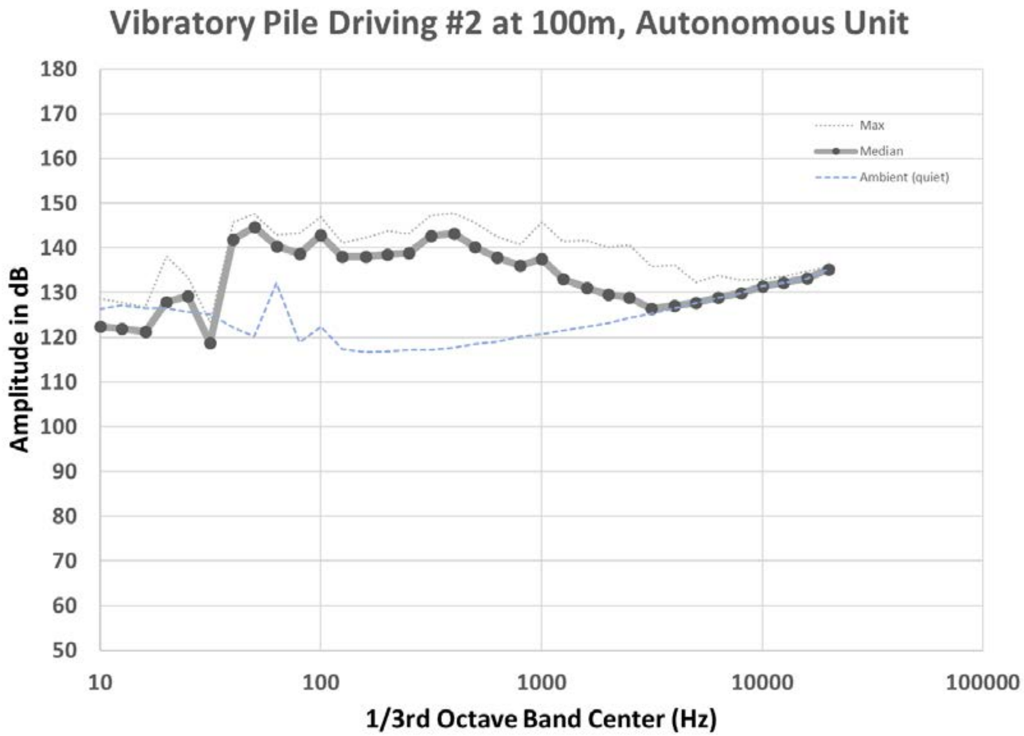

Vibratory Pile Driving #4 at 10m, Shallow Hydrophone
Amplitude in dB
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)

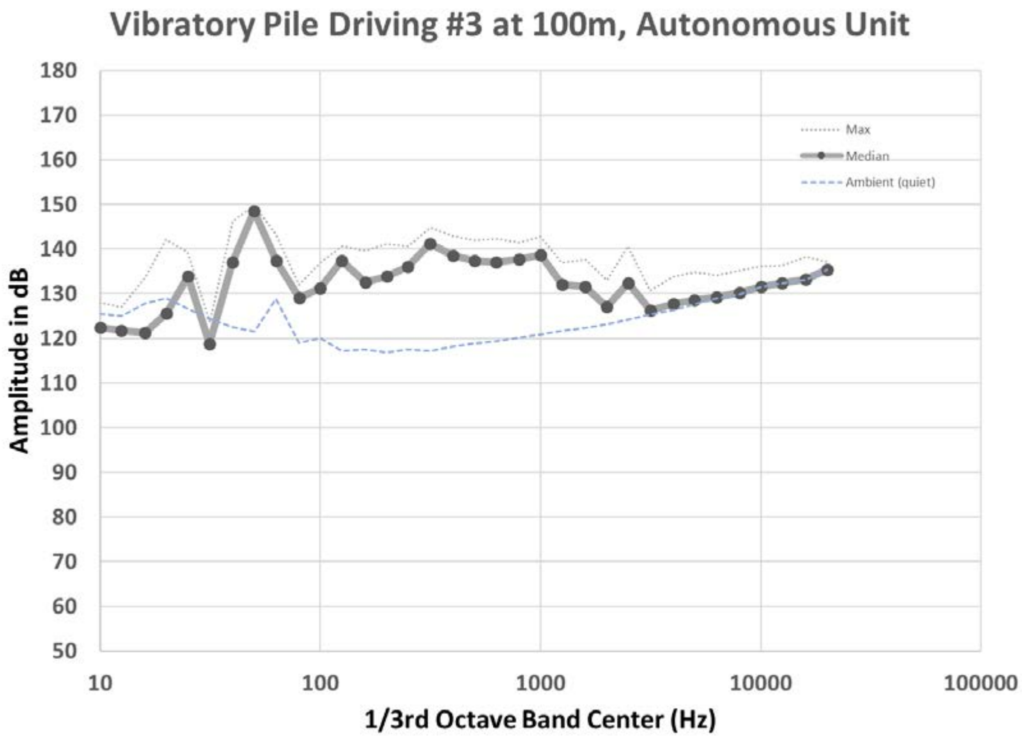

Vibratory Pile Driving #4 at 10m, Deep Hydrophone
Amplitude in dB
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)

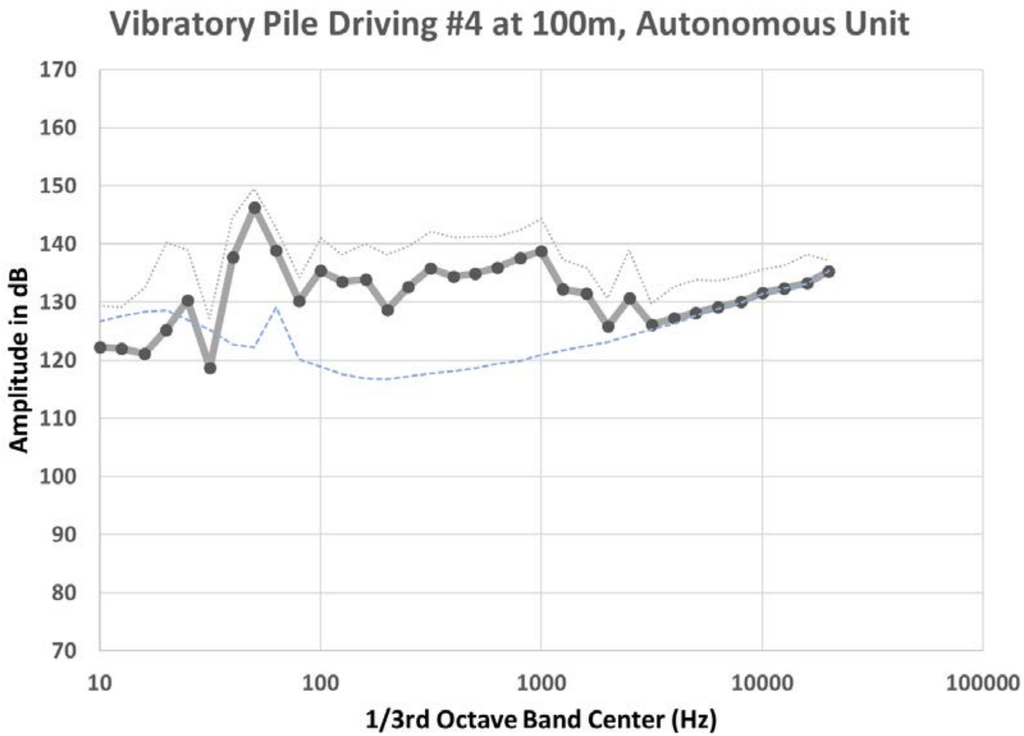

Vibratory Pile Driving #4 at 7km, Shallow Hydrophone
Amplitude in dB
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)

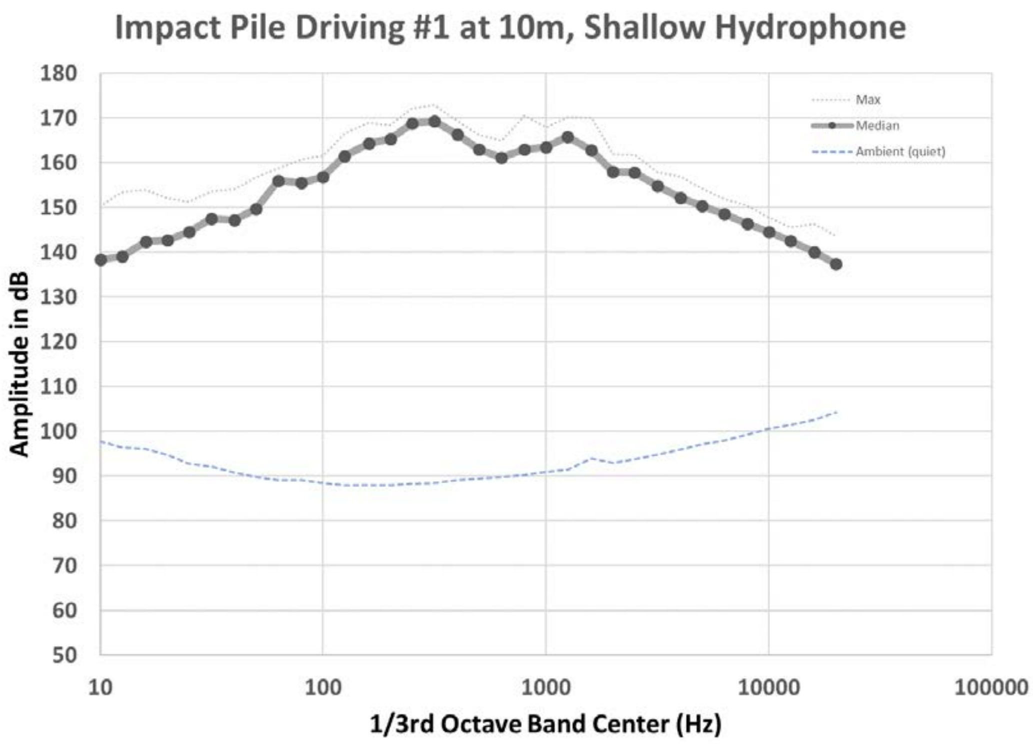

Vibratory Pile Driving #4 at 7km, Deep Hydrophone
Amplitude in dB
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)

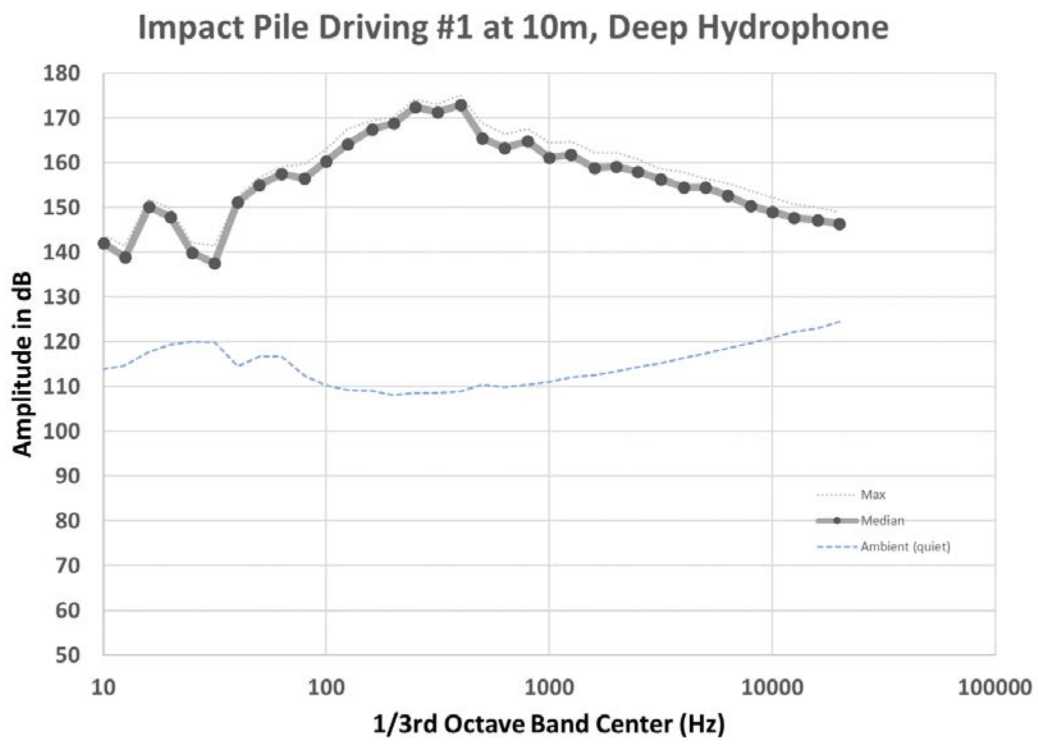

Vibratory Pile Driving #1 at 100m, Autonomous Unit
Max
Median
Ambient (quiet)
Amplitude in dB
1/3rd Octave Band Center (Hz)

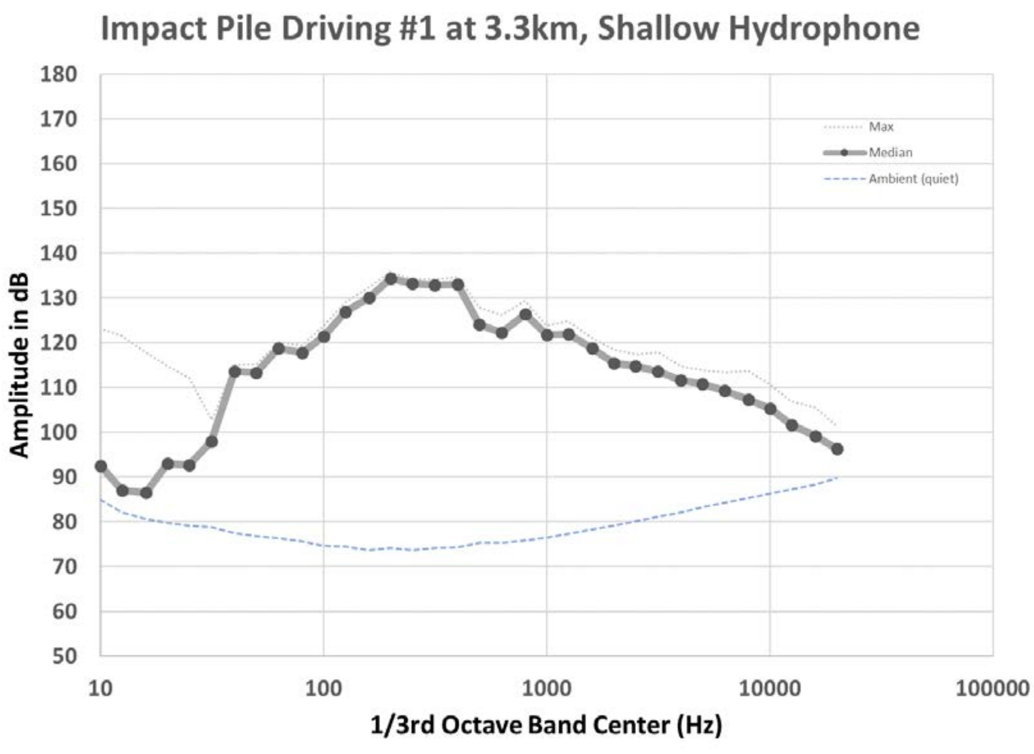

Vibratory Pile Driving #2 at 100m, Autonomous Unit
Max
Median
Ambient (quiet)
Amplitude in dB
1/3rd Octave Band Center (Hz)

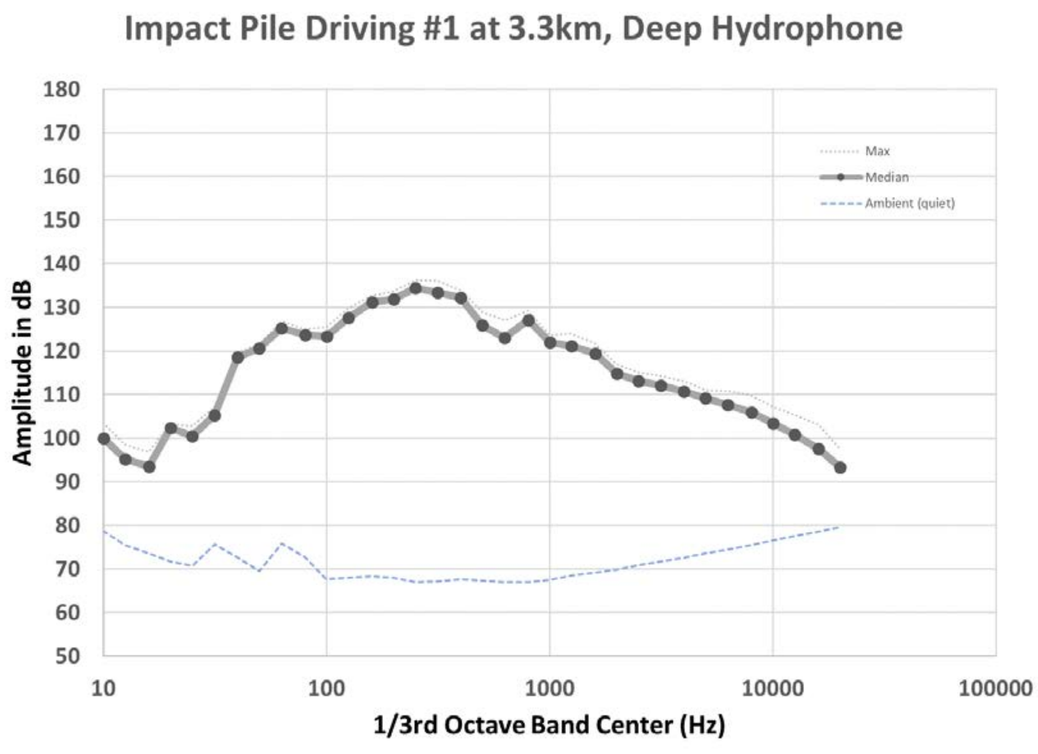

Vibratory Pile Driving #3 at 100m, Autonomous Unit
Max
Median
Ambient (quiet)
Amplitude in dB
1/3rd Octave Band Center (Hz)

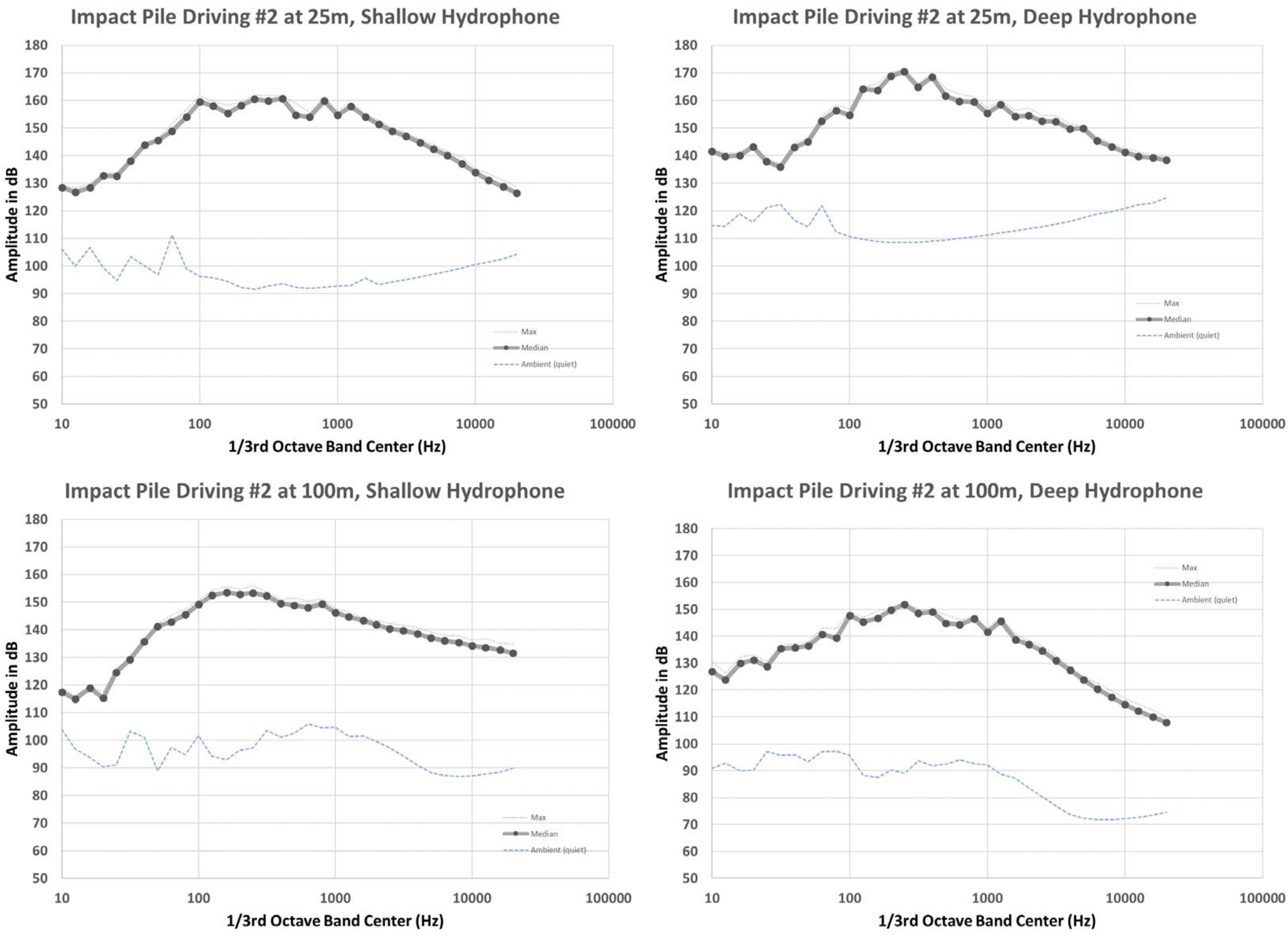

Vibratory Pile Driving #4 at 100m, Autonomous Unit
Amplitude in dB
1/3rd Octave Band Center (Hz)

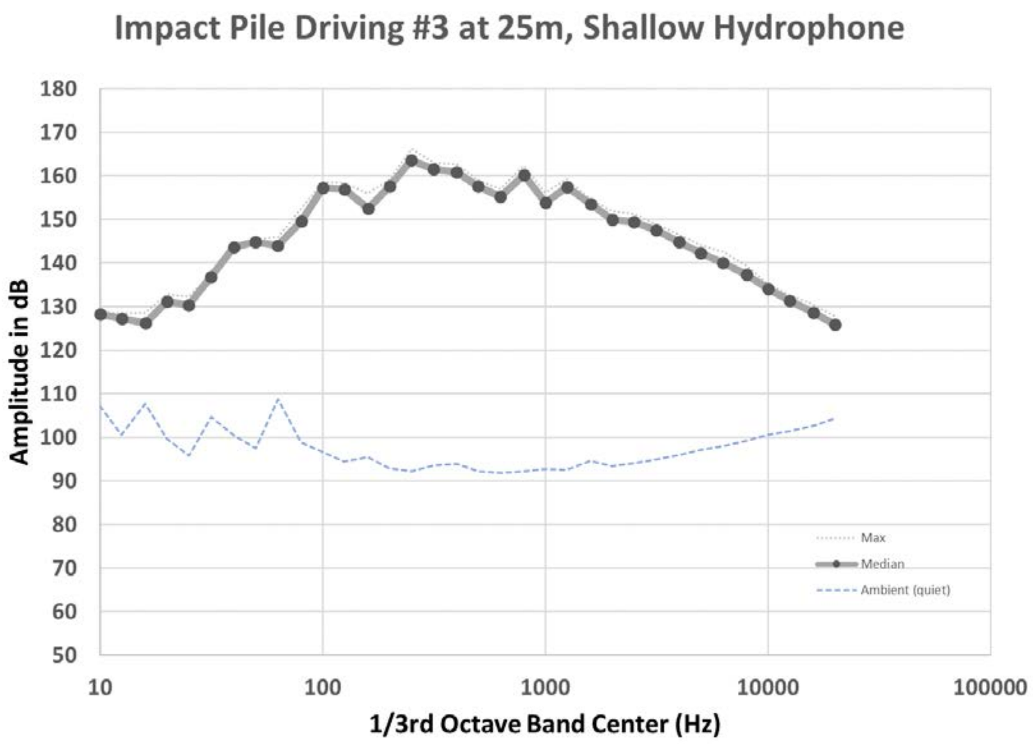

Impact Pile Driving #1 at 10m, Shallow Hydrophone
Max
Median
Ambient (quiet)
Amplitude in dB
1/3rd Octave Band Center (Hz)

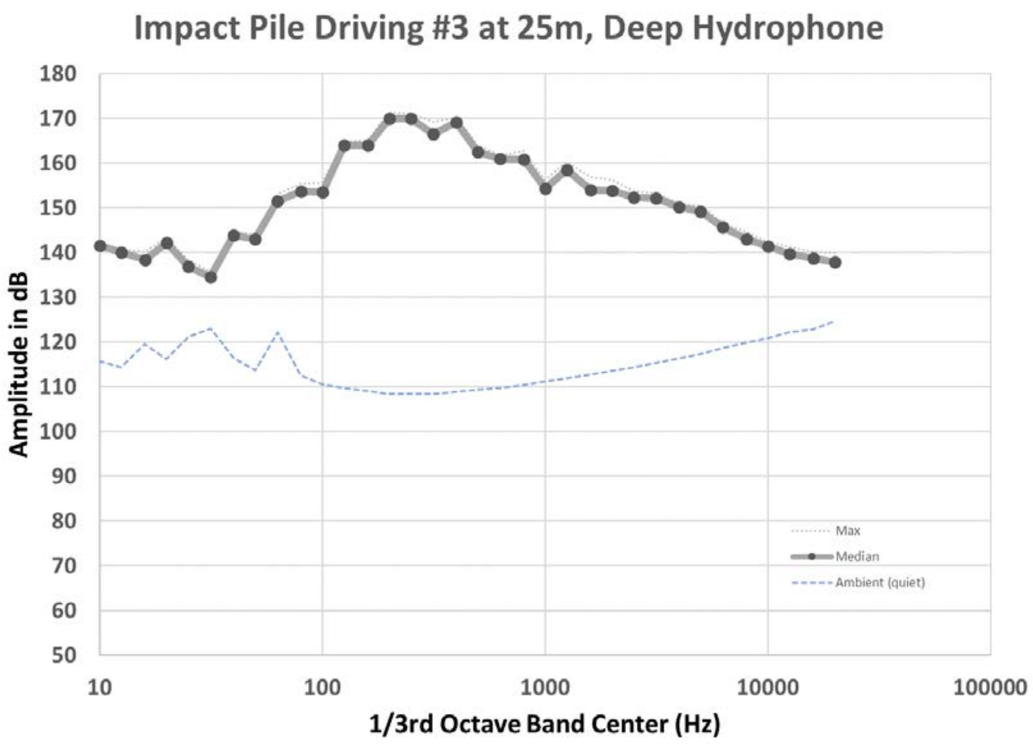

Impact Pile Driving #1 at 10m, Deep Hydrophone
Max
Median
Ambient (quiet)
Amplitude in dB
1/3rd Octave Band Center (Hz)

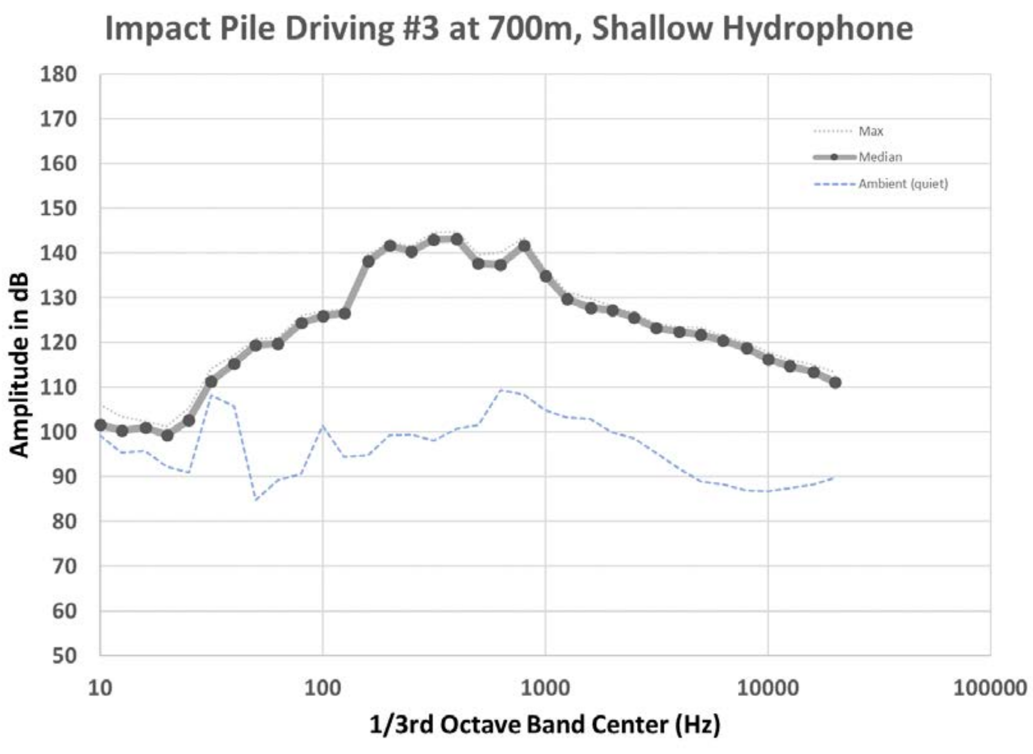

Impact Pile Driving #1 at 3.3km, Shallow Hydrophone
Max
Median
Ambient (quiet)
Amplitude in dB
1/3rd Octave Band Center (Hz)

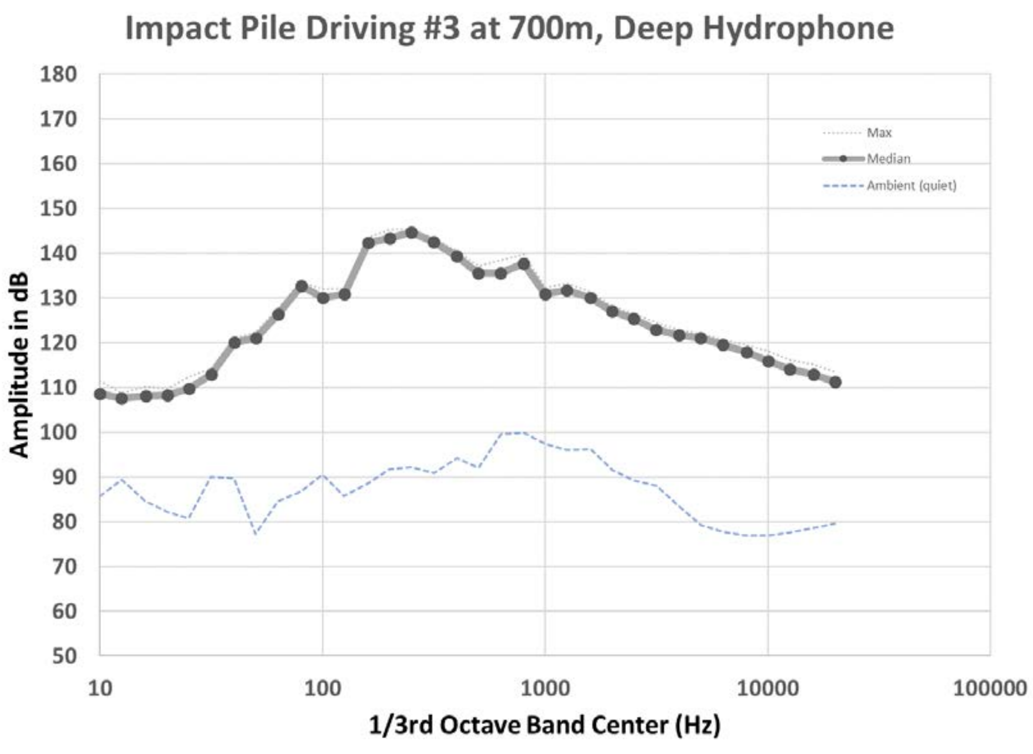

Impact Pile Driving #1 at 3.3km, Deep Hydrophone
Max
Median
Ambient (quiet)
Amplitude in dB
1/3rd Octave Band Center (Hz)

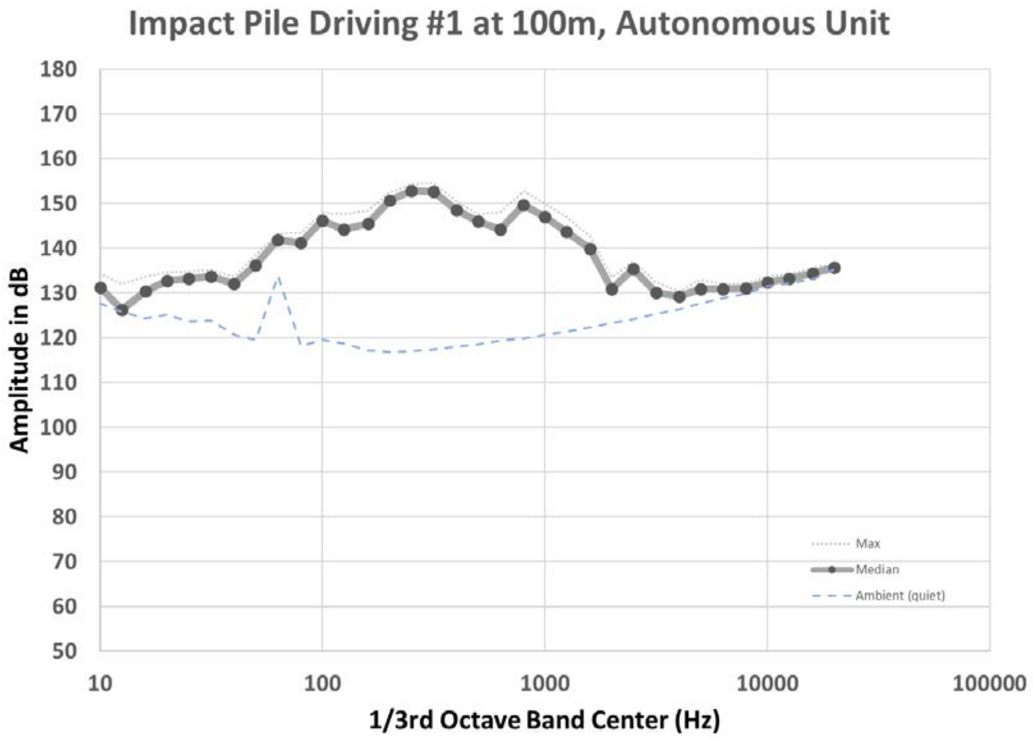

Impact Pile Driving #2 at 25m, Shallow Hydrophone
Impact Pile Driving #2 at 25m, Deep Hydrophone
Impact Pile Driving #2 at 100m, Shallow Hydrophone
Impact Pile Driving #2 at 100m, Deep Hydrophone
Amplitude in dB
1/3rd Octave Band Center (Hz)
50
60
70
80
90
100
110
120
130
140
150
160
170
180
10
100
1000
10000
100000
Max
Median
Ambient (quiet)


Impact Pile Driving #3 at 25m, Shallow Hydrophone
180
170
160
150
140
130
120
110
100
90
80
70
60
50
Amplitude in dB
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)

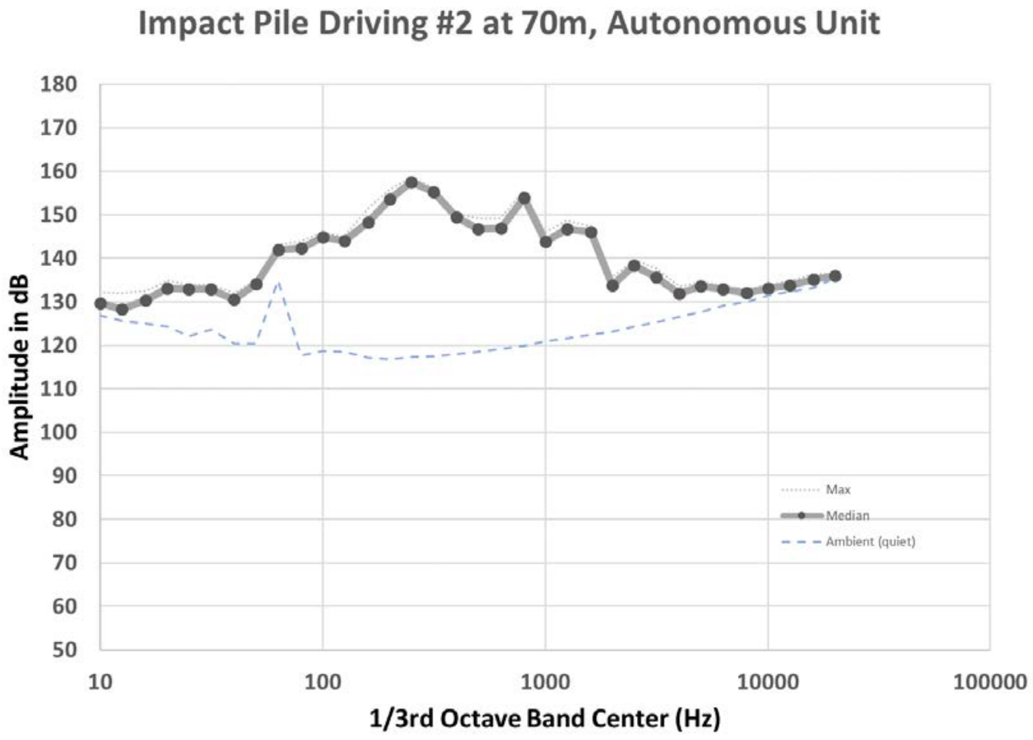

Impact Pile Driving #3 at 25m, Deep Hydrophone
180
170
160
150
140
130
120
110
100
90
80
70
60
50
Amplitude in dB
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)


Impact Pile Driving #3 at 700m, Shallow Hydrophone
180
170
160
150
140
130
120
110
100
90
80
70
60
50
Amplitude in dB
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)

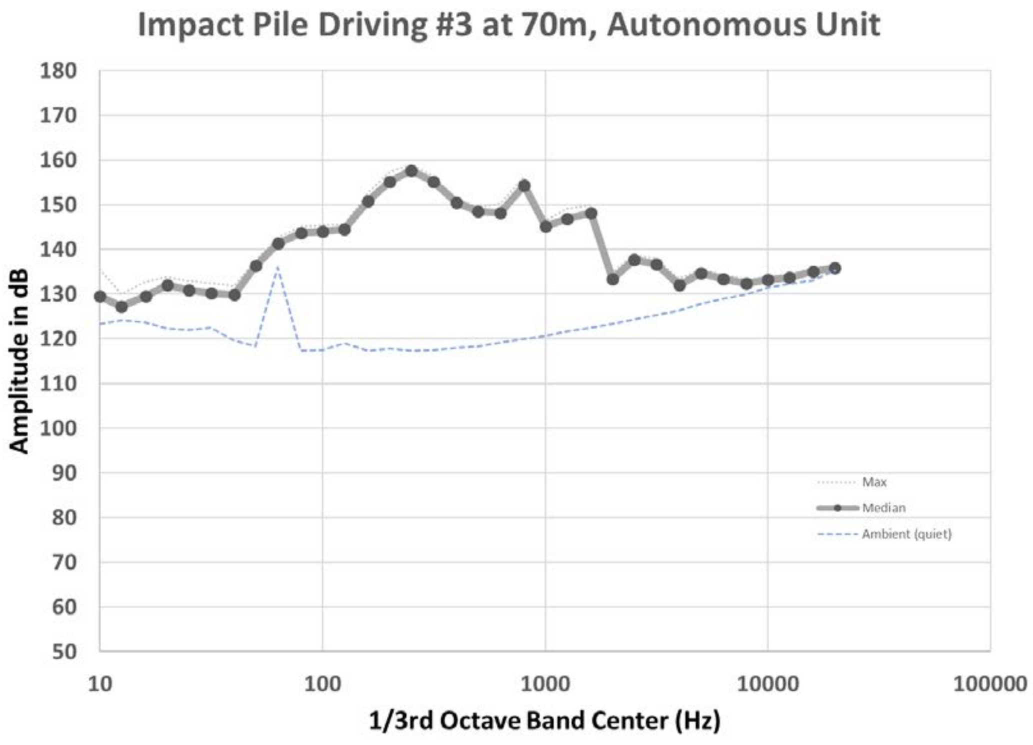

Impact Pile Driving #3 at 700m, Deep Hydrophone
180
170
160
150
140
130
120
110
100
90
80
70
60
50
Amplitude in dB
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)



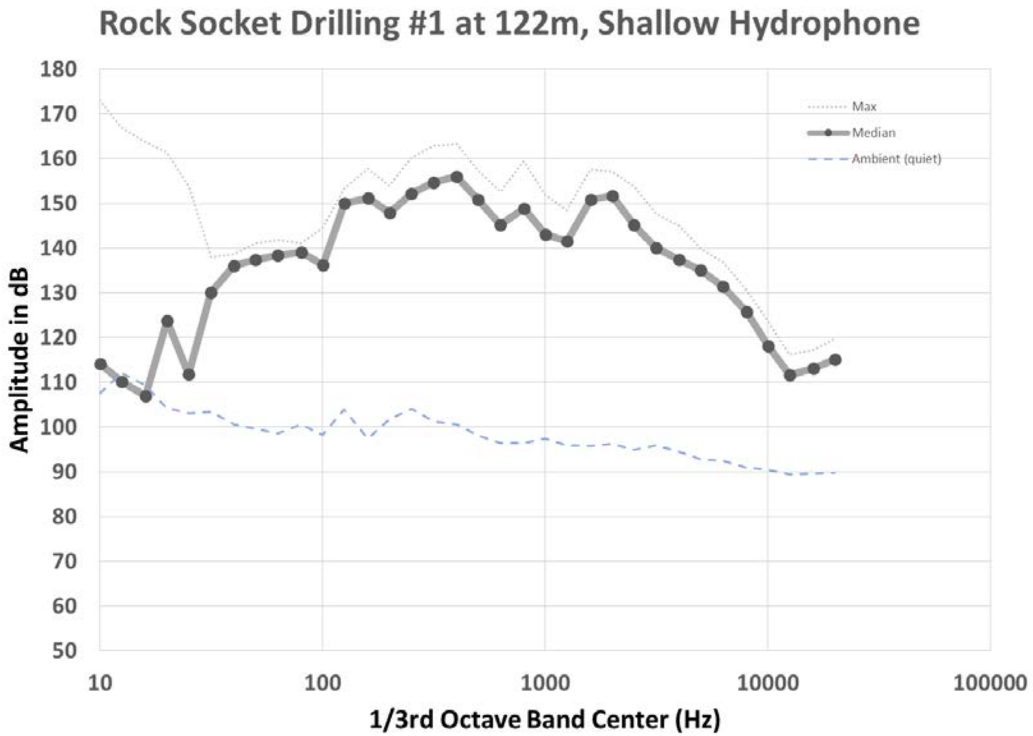
Impact Pile Driving #1 at 100m, Autonomous Unit
Amplitude in dB
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)

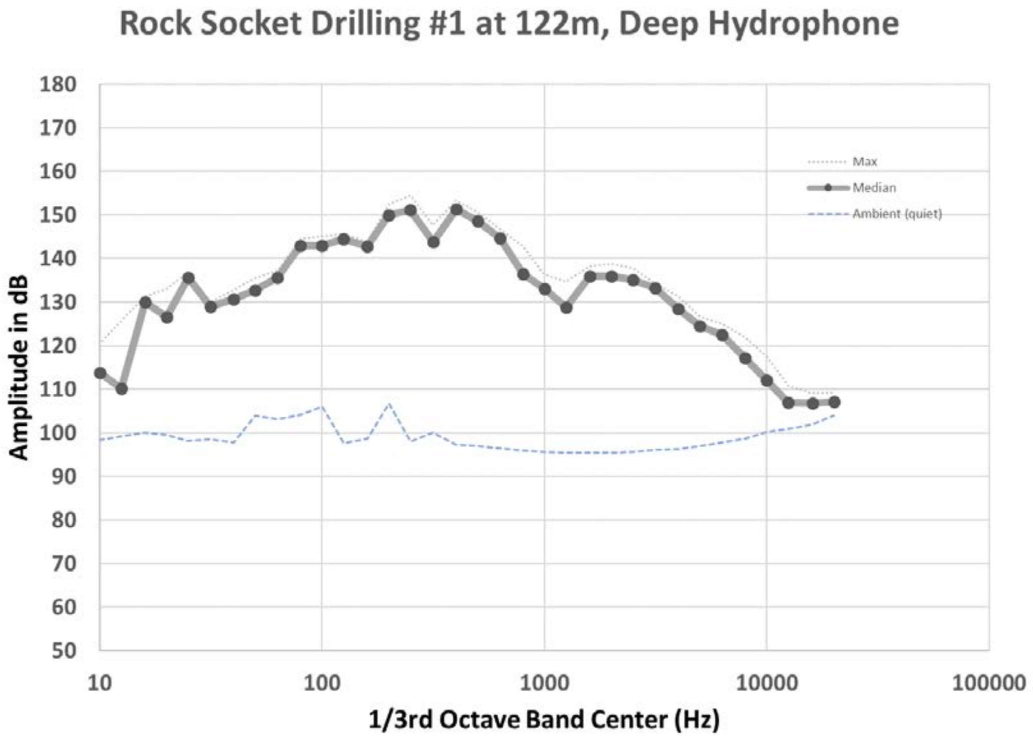


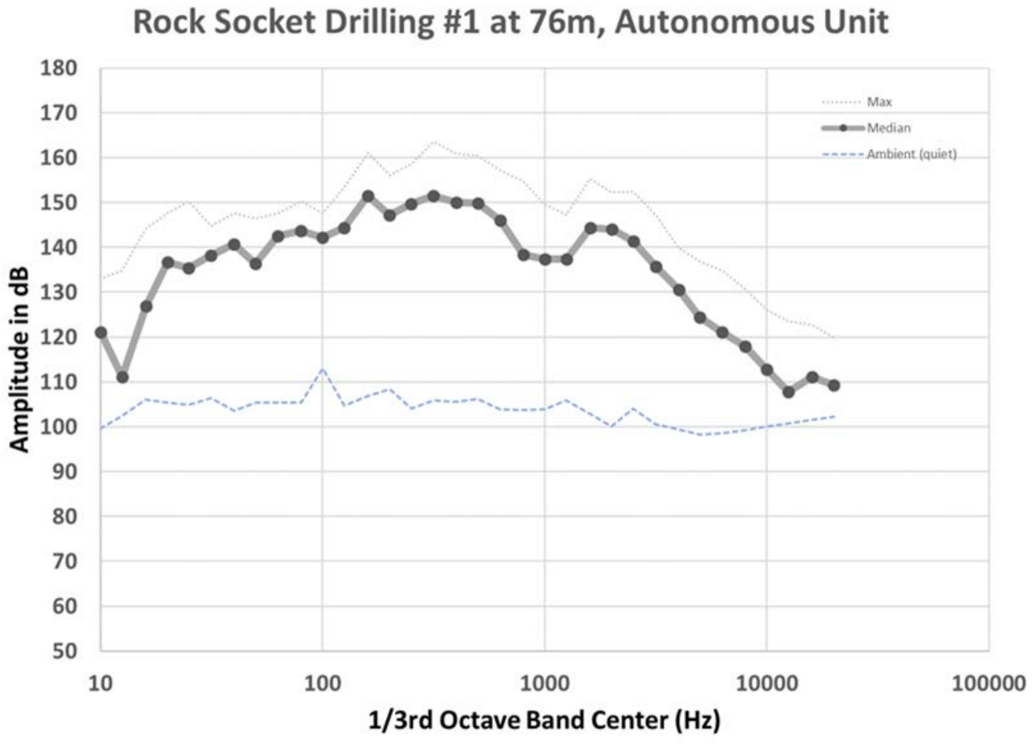
Impact Pile Driving #2 at 70m, Autonomous Unit
Amplitude in dB
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)

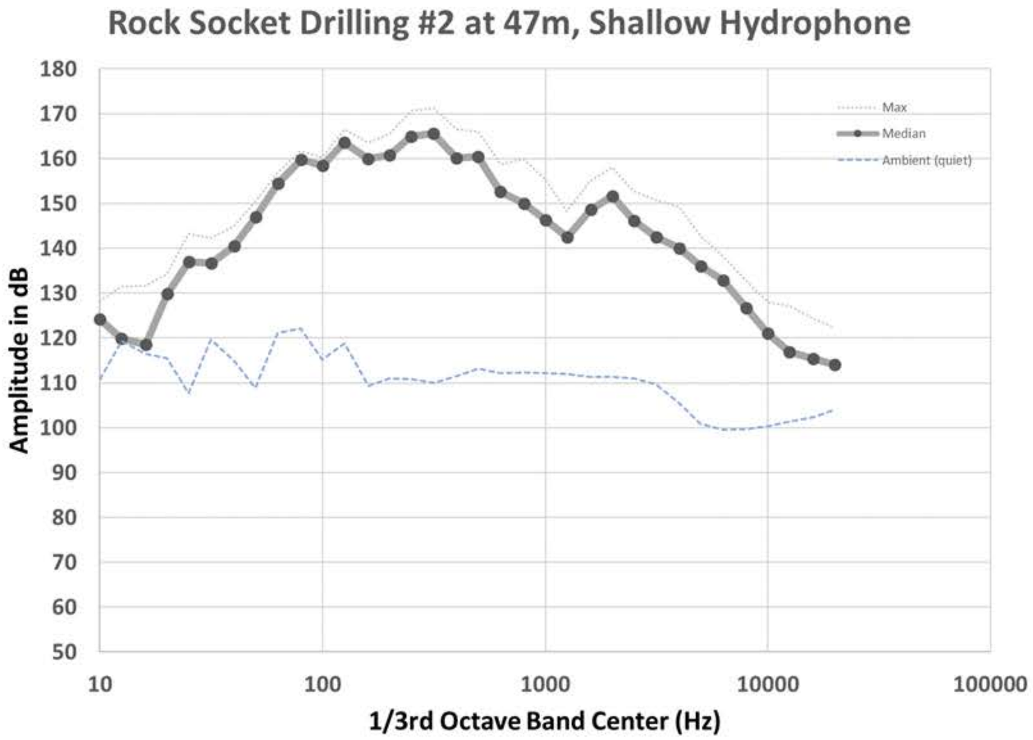


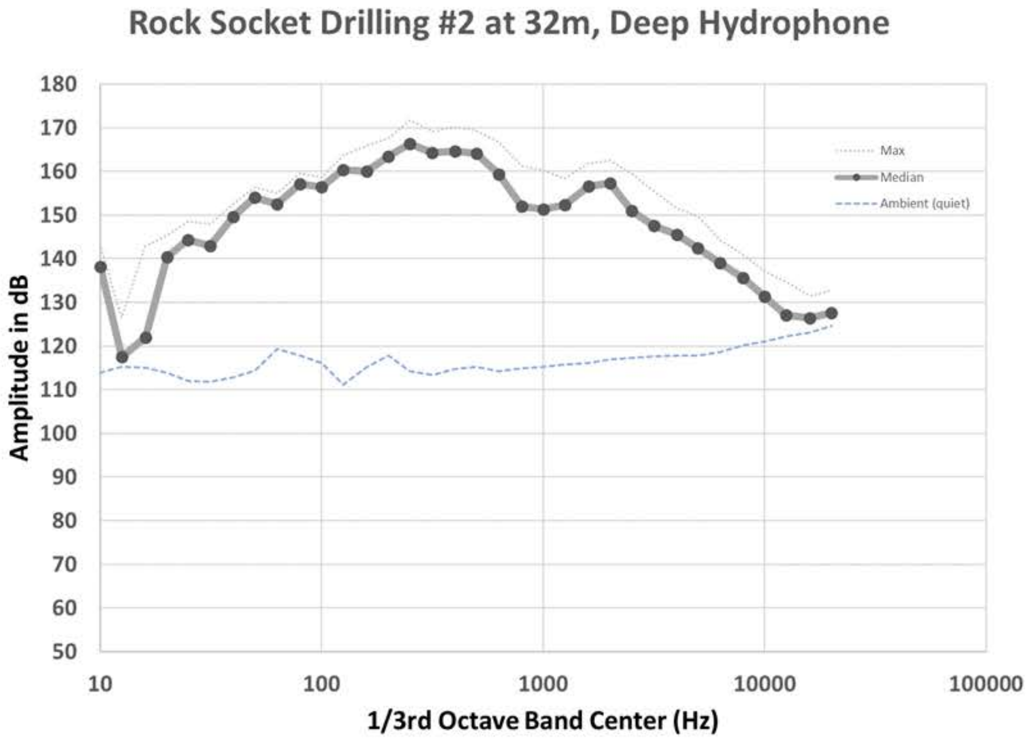
Impact Pile Driving #3 at 70m, Autonomous Unit
Amplitude in dB
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)

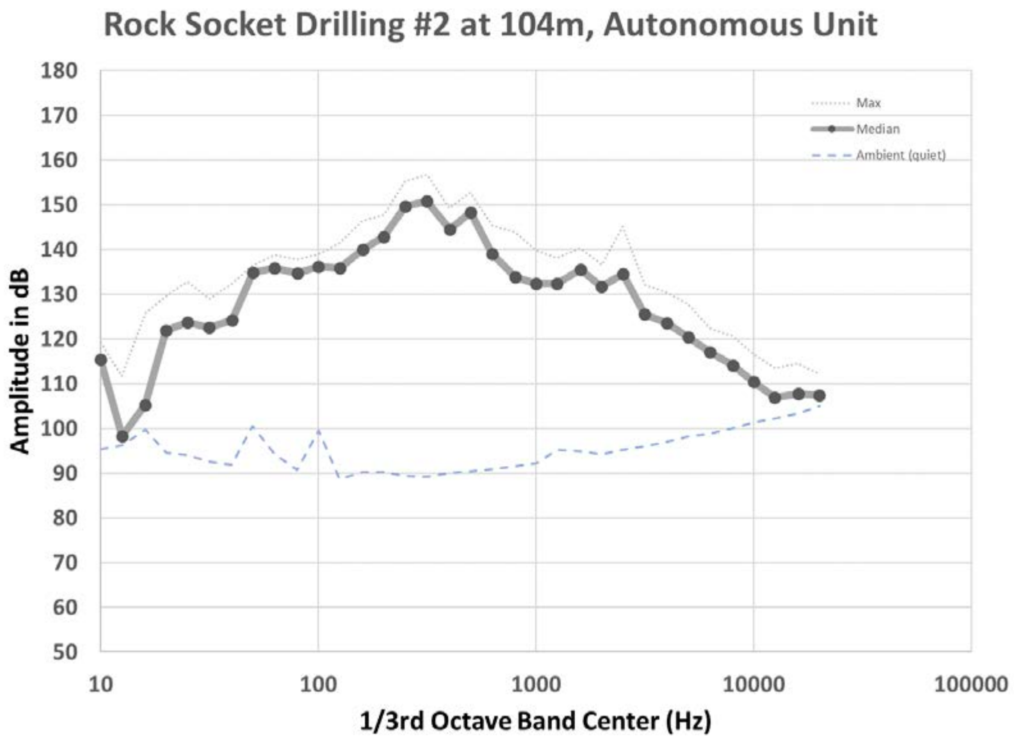

Rock Socket Drilling #1 at 122m, Shallow Hydrophone
Max
Median
Ambient (quiet)
Amplitude in dB
180
170
160
150
140
130
120
110
100
90
80
70
60
50
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)

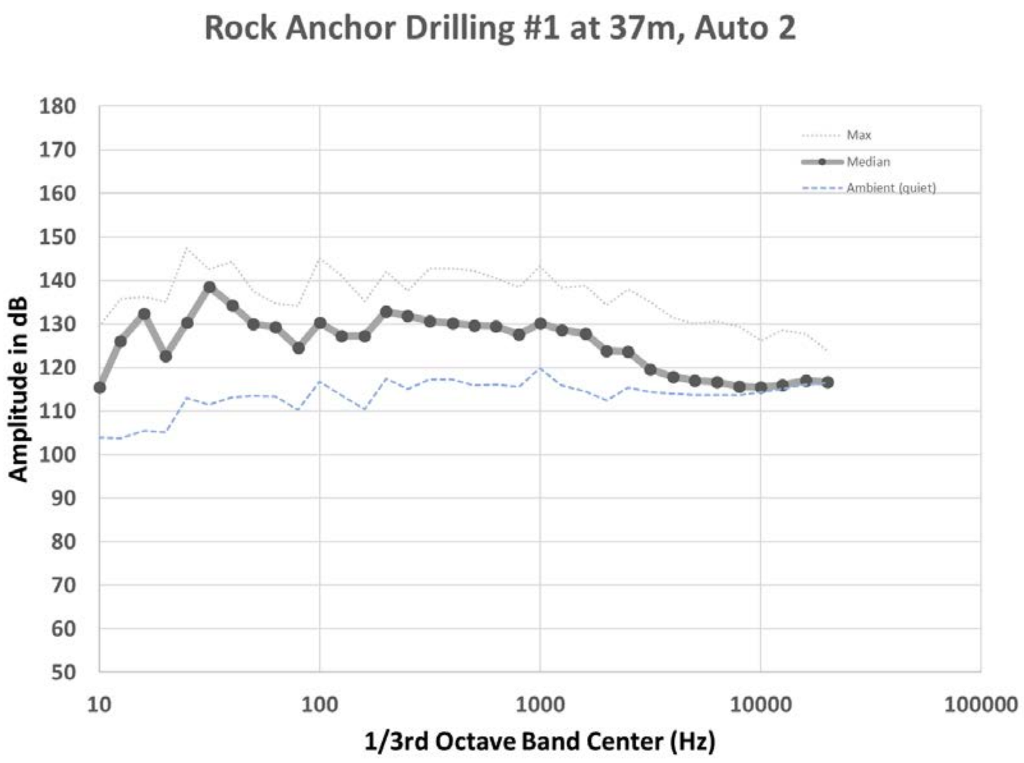

Rock Socket Drilling #1 at 122m, Deep Hydrophone
Max
Median
Ambient (quiet)
Amplitude in dB
180
170
160
150
140
130
120
110
100
90
80
70
60
50
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)


Rock Socket Drilling #1 at 76m, Autonomous Unit
Max
Median
Ambient (quiet)
Amplitude in dB
180
170
160
150
140
130
120
110
100
90
80
70
60
50
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)

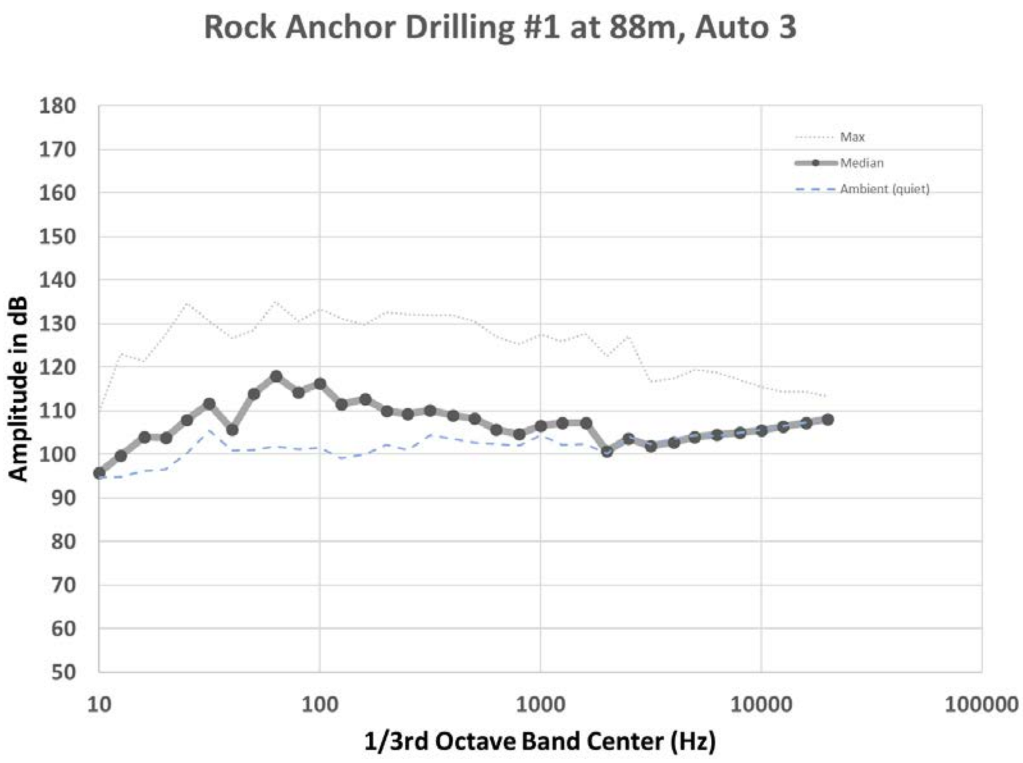

Rock Socket Drilling #2 at 47m, Shallow Hydrophone
180
170
160
150
140
130
120
110
100
90
80
70
60
50
Amplitude in dB
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)


Rock Socket Drilling #2 at 32m, Deep Hydrophone
180
170
160
150
140
130
120
110
100
90
80
70
60
50
Amplitude in dB
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)

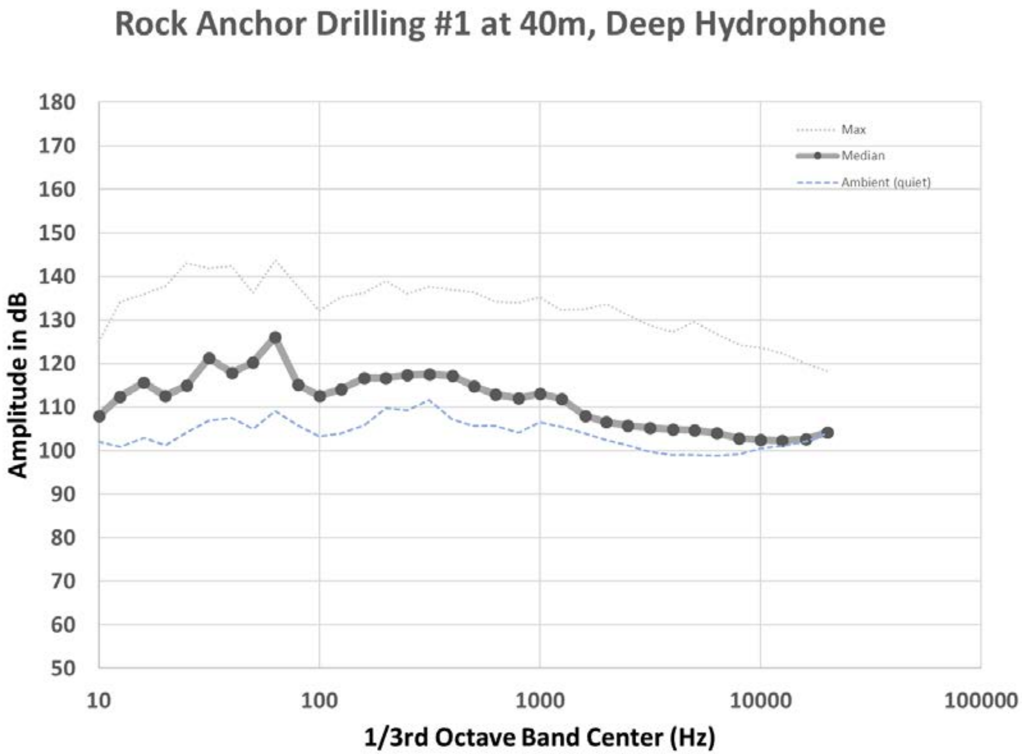

Rock Socket Drilling #2 at 104m, Autonomous Unit
180
170
160
150
140
130
120
110
100
90
80
70
60
50
Amplitude in dB
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)
Max
Median
Ambient (quiet)



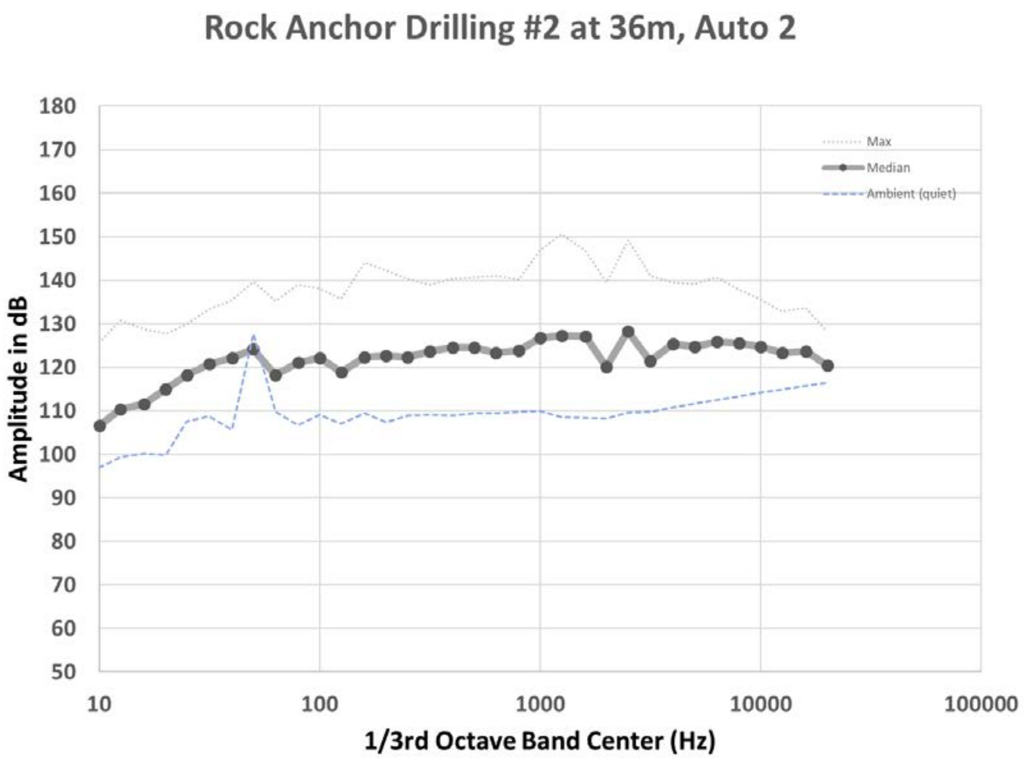
Rock Anchor Drilling #1 at 37m, Auto 2
Max
Median
Ambient (quiet)
Amplitude in dB
180
170
160
150
140
130
120
110
100
90
80
70
60
50
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)

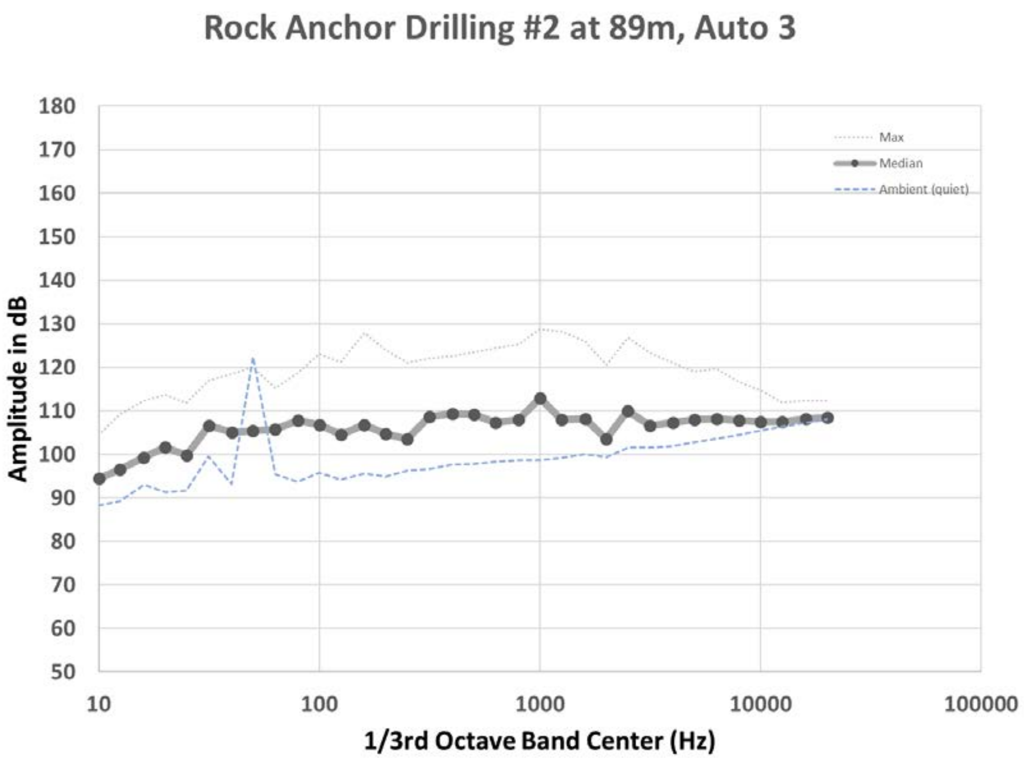


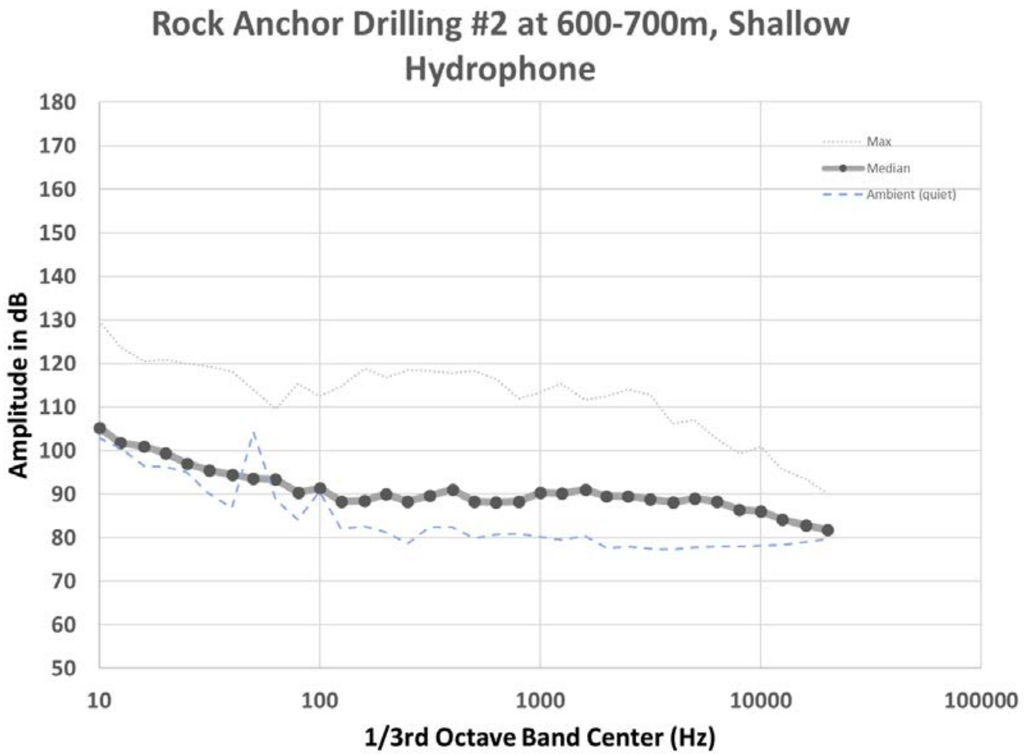
Rock Anchor Drilling #1 at 88m, Auto 3
Max
Median
Ambient (quiet)
Amplitude in dB
180
170
160
150
140
130
120
110
100
90
80
70
60
50
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)

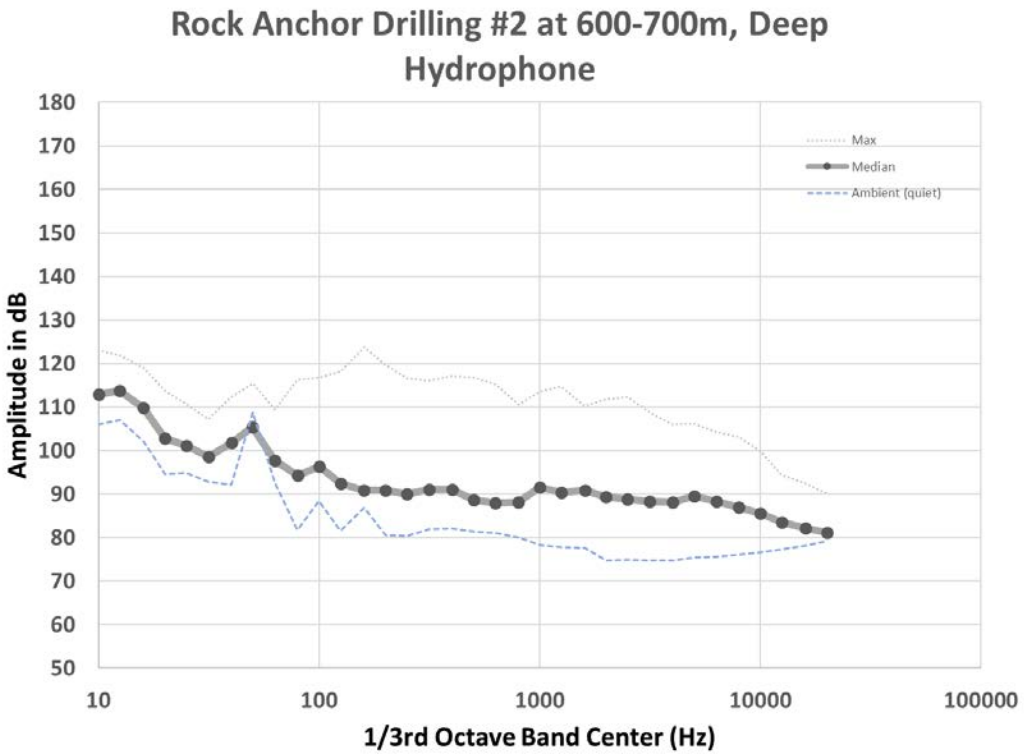


Rock Anchor Drilling #1 at 40m, Deep Hydrophone
Max
Median
Ambient (quiet)
Amplitude in dB
180
170
160
150
140
130
120
110
100
90
80
70
60
50
10
100
1000
10000
100000
1/3rd Octave Band Center (Hz)

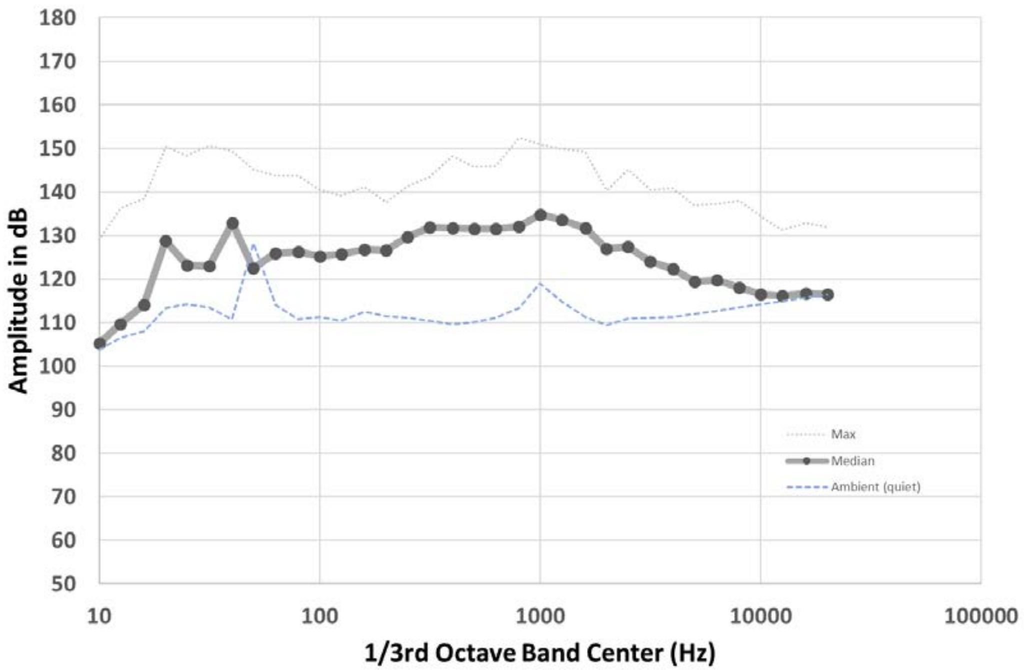

Rock Anchor Drilling #2 at 36m, Auto 2
Max
Median
Ambient (quiet)
Amplitude in dB
1/3rd Octave Band Center (Hz)


Rock Anchor Drilling #2 at 89m, Auto 3
Max
Median
Ambient (quiet)
Amplitude in dB
1/3rd Octave Band Center (Hz)

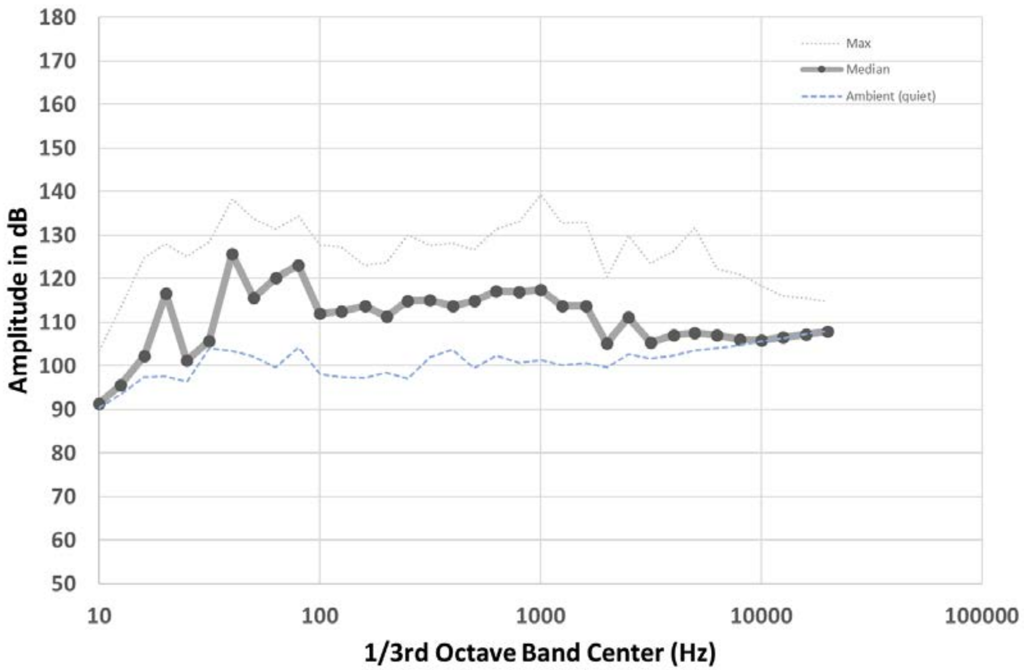

Rock Anchor Drilling #2 at 600-700m, Shallow Hydrophone
Max
Median
Ambient (quiet)
Amplitude in dB
1/3rd Octave Band Center (Hz)


Rock Anchor Drilling #2 at 600-700m, Deep Hydrophone
Max
Median
Ambient (quiet)
Amplitude in dB
1/3rd Octave Band Center (Hz)

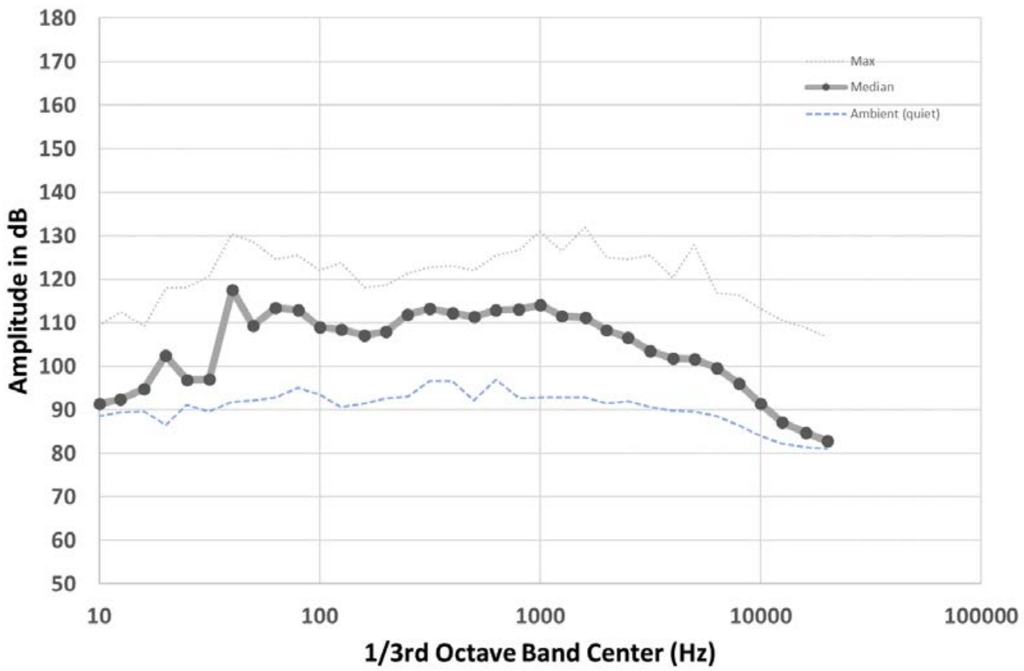
Rock Anchor Drilling #3 at 36m, Auto 2



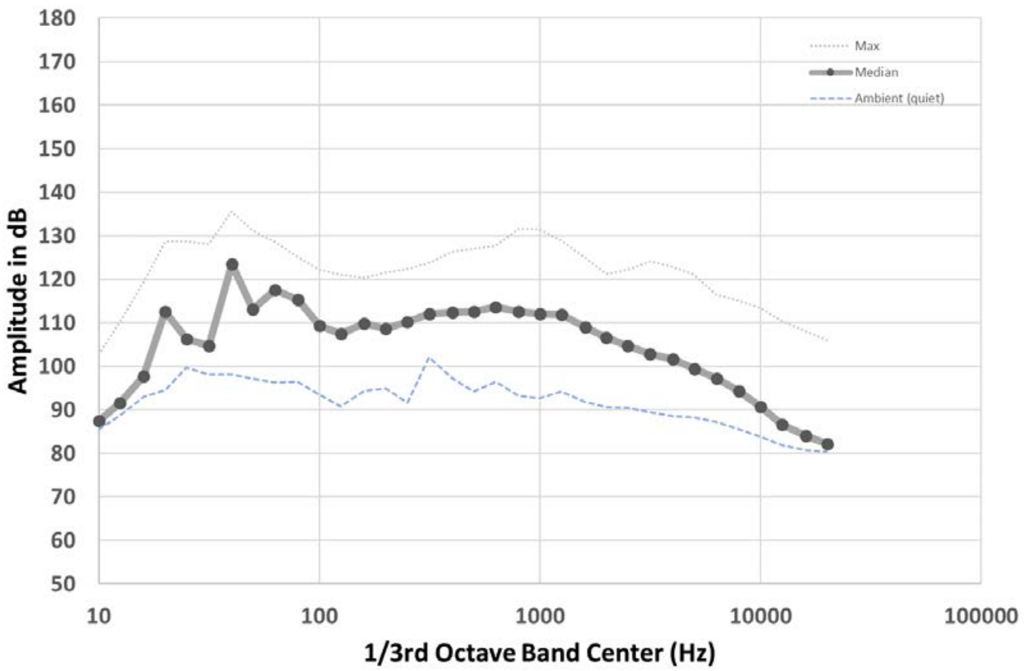
Rock Anchor Drilling #3 at 91m, Auto 3



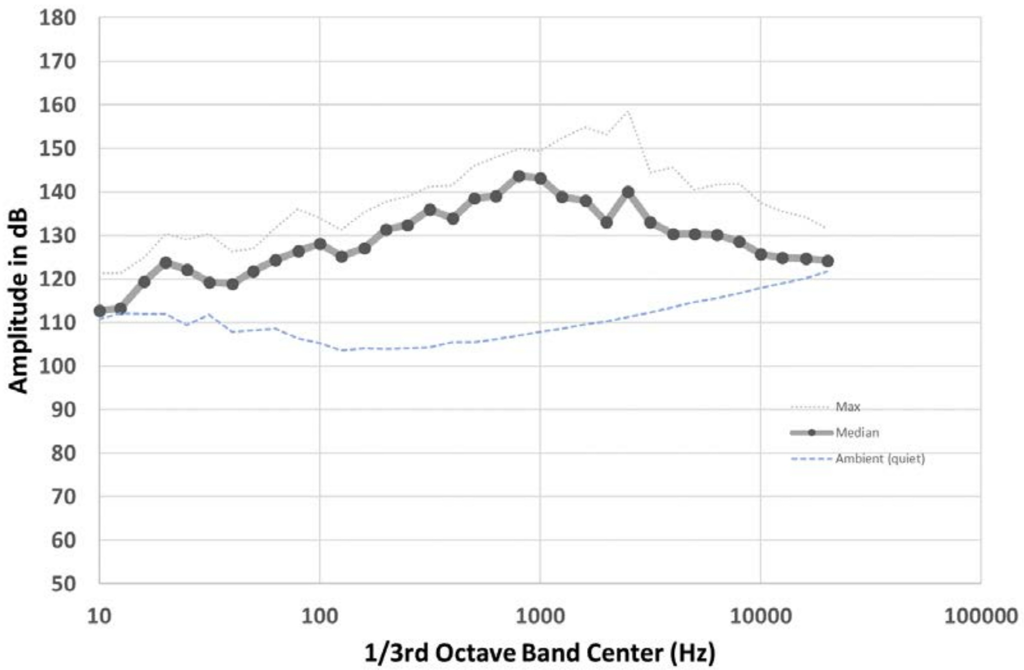
Rock Anchor Drilling #3 at 122m, Shallow Hydrophone



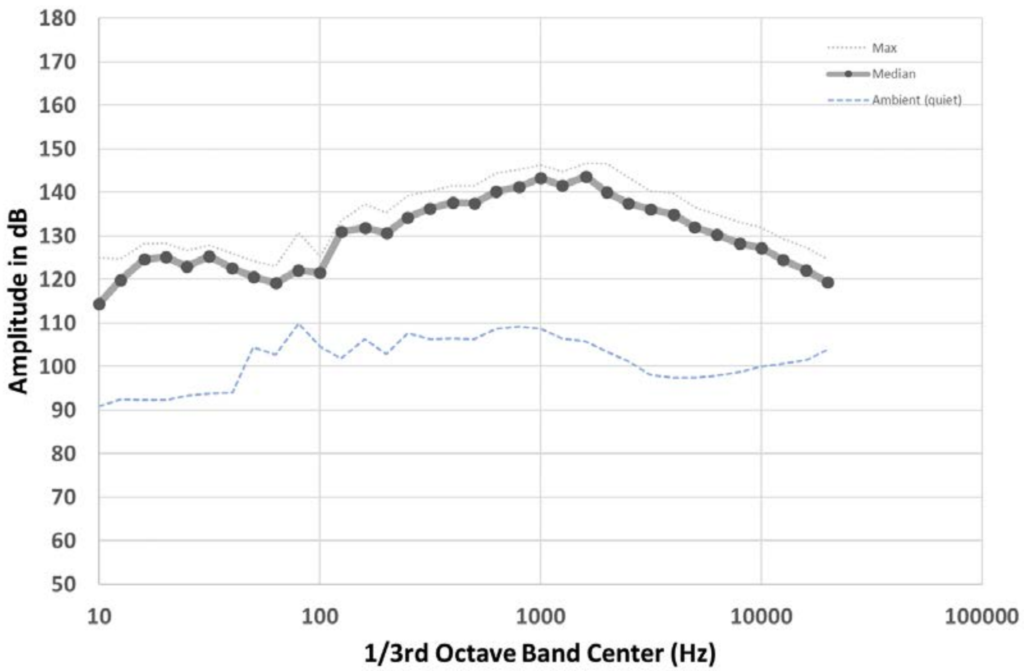
Rock Anchor Drilling #3 at 116m, Deep Hydrophone



Anchor Casing Installation at 91m, Auto 3



Anchor Casing Installation at 48m, Deep Hydrophone



Appendix E – Power Spectrum Density Distributions

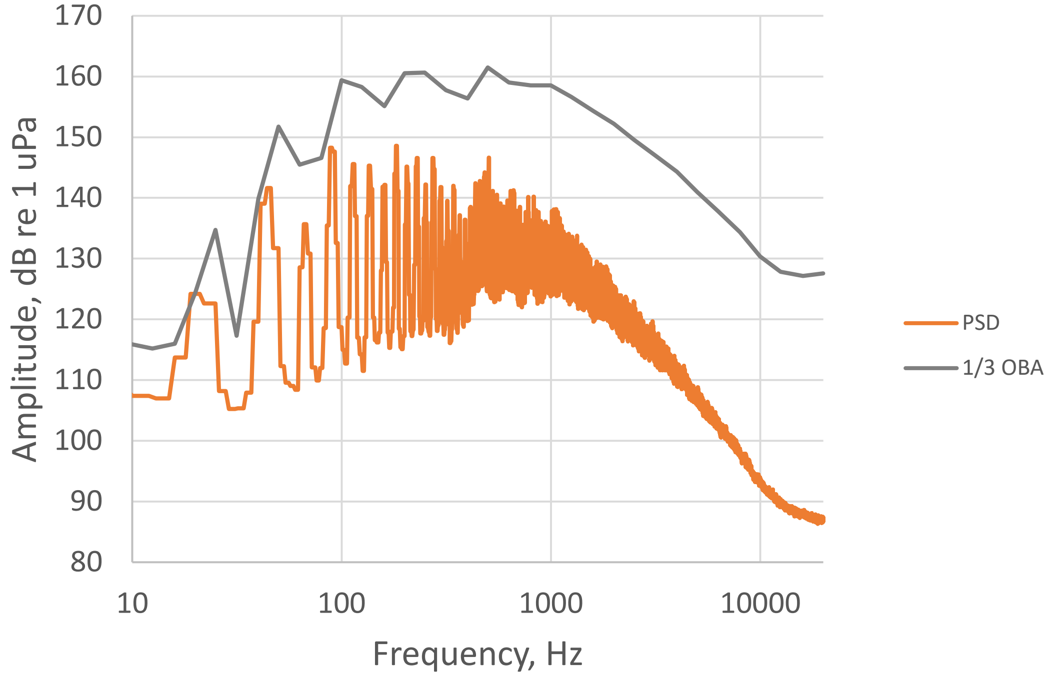


Figure E-1. Power Spectral Density distribution of vibratory pile driving over a one-minute interval at 10 meters.

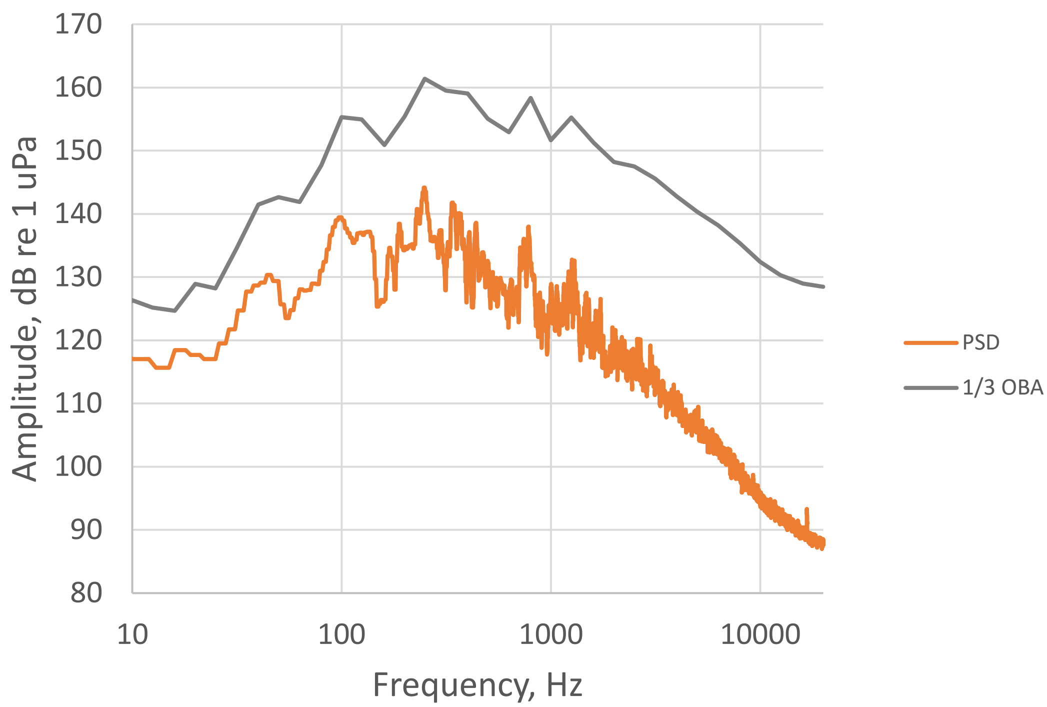


Figure E-2. Power Spectral Density distribution of impact pile driving over a one-minute interval at 25 meters.

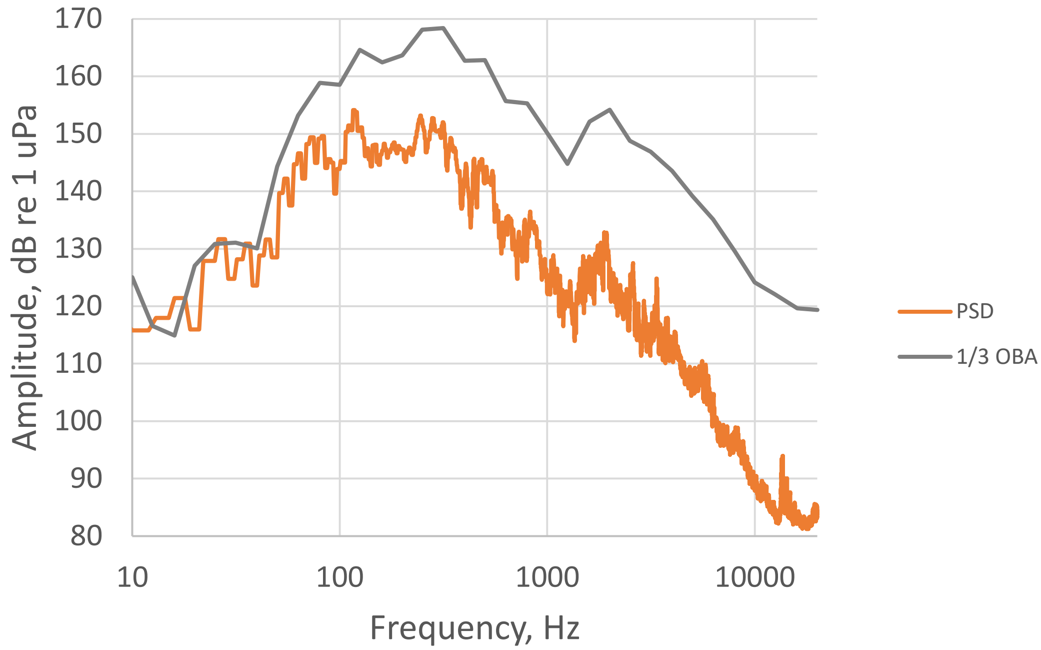


Figure E-3. Power Spectral Density distribution of rock socket drilling over a one-minute interval at 47 meters.

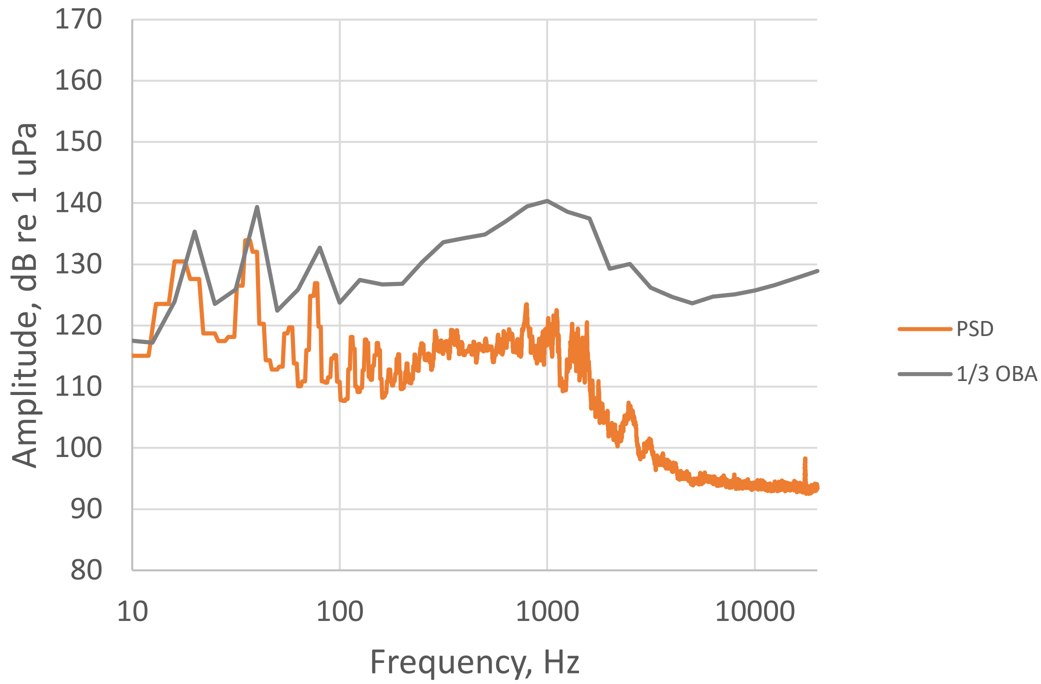


Figure E-4. Power Spectral Density distribution of rock anchor drilling over a one-minute interval at 47 meters.

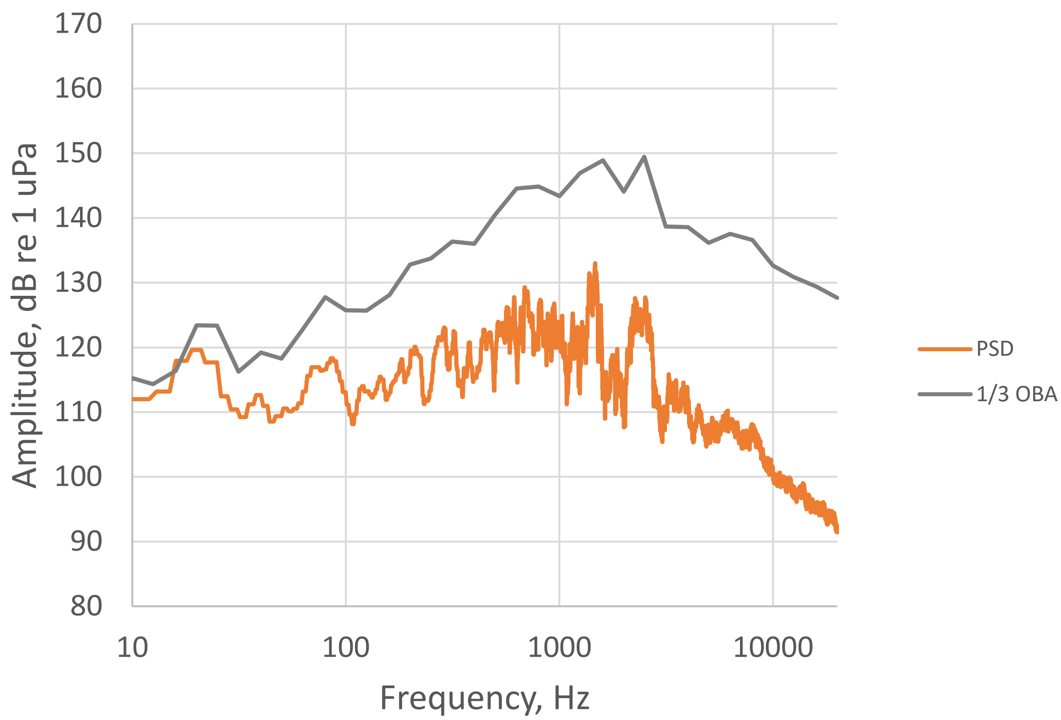


Figure E-5. Power Spectral Density distribution of rock anchor drill casing installation over a one-minute interval at 91 meters.