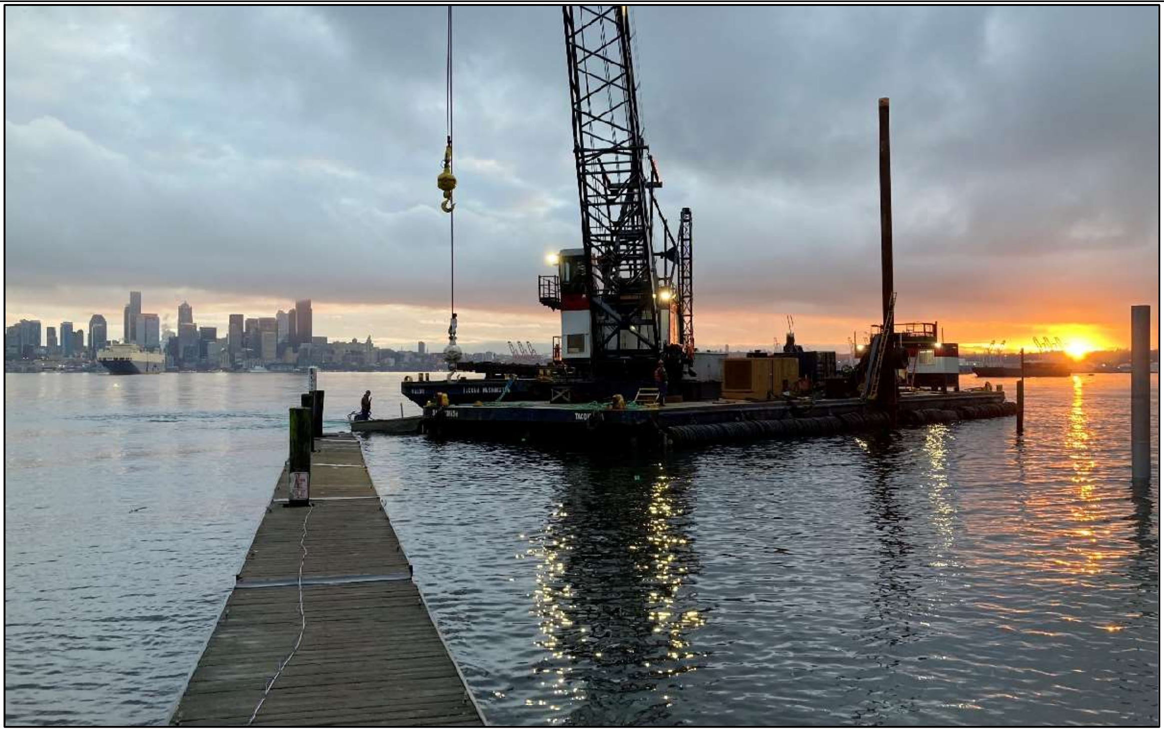
Attachment C
Don Armeni Acoustic Report



DON ARMENI BOAT RAMP PILING AND DOCK REPLACMENT ACOUSTIC MONITORING REPORT

May 7, 2024

Prepared For:

City of Seattle Department of Parks and Recreation

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1.0 EXECUTIVE SUMMARY

This Acoustic Monitoring Report (Report) summarizes airborne and underwater sound levels measured during the removal of timber piles with an ICE Model 416L Vibratory Driver/Extractor and during the installation of 16-inch diameter steel piles with an APE Model 200 Vibratory Pile Driver. These measurements were made as part of the Don Armeni Boat Ramp Piling and Dock Replacement Project (Project).

During vibratory pile removal, unweighted underwater 10-second root mean squared (RMS) sound levels measured by the near-field hydrophone, located 33 feet (10 meters) from the piles ranged from 134 to 164 decibels (dB) re: 1 micropascal (μPa). Ranges of underwater sound levels for each marine mammal hearing group and unweighted sound levels measured during vibratory pile removal are shown in Table 1. The highest daily unweighted cSEL measured during pile removal was 181 dB re: 1 μPa and occurred on February 5, 2024. The median airborne 1-second RMS sound level was 92 dB re: 20 μPa at 50 feet (15 meters) from pile removal.

Table 1 Underwater Sound Levels – Vibratory Pile Removal, min-max (median) dB re: 1 μPa

Metric	Unweighted	Cetaceans			Pinnipeds	
		Low-Frequency	Mid-Frequency	High-Frequency	Phocid	Otariid
Peak	153-177 (167)	144-168 (156)	149-174 (163)	149-174 (163)	146-169 (157)	145-169 (156)
RMS	134-164 (149)	123-144 (132)	129-158 (142)	129-159 (143)	123-148 (135)	121-145 (133)
SEL	144-174 (159)	133-154 (142)	139-168 (152)	139-169 (153)	133-158 (145)	131-155 (143)

Note: Sound levels are normalized to 33 feet (10 meters) from piles

The median SEL measured by the far-field hydrophone was used to estimate the daily cSEL if vibratory pile removal were to occur for the maximum allowable time per day (2 hours 40 minutes). The resulting daily cSEL and the median RMS sound levels were used to estimate the distances for underwater sounds from pile removal to dissipate to the injury (Level A) and disturbance (Level B) marine mammal thresholds. It was estimated that up to 39 feet (12 meters) may be needed for sounds to dissipate to the Level A thresholds and up to 297 feet (91 meters) may be required to reach Level B thresholds.

Vibratory pile driving of the 16-inch diameter piles produced in-water unweighted RMS sound levels that ranged from 125 to 166 dB re: 1 μPa. The highest daily unweighted cSEL was 194 dB re: 1 μPa, which occurred on February 7, 2024. The range and median underwater sound levels for each marine mammal hearing group, and unweighted sound levels are shown in Table 2. The median 1-second airborne RMS sound level measured during vibratory pile driving was 93 dB re: 20 μPa at 50 feet (15 meters) from the piles.

Table 2 Underwater Sound Levels – Vibratory Pile Driving, min-max (median) dB re: 1 μPa

Metric	Unweighted	Cetaceans			Pinnipeds	
		Low-Frequency	Mid-Frequency	High-Frequency	Phocid	Otariid
Peak	152-193 (163)	146-187 (156)	149-190 (158)	149-190 (158)	147-188 (155)	147-187 (155)
RMS	125-166 (147)	116-161 (141)	120-164 (142)	120-163 (142)	116-162 (139)	116-161 (140)
SEL	135-176 (157)	126-171 (151)	130-174 (152)	130-173 (152)	126-172 (149)	126-171 (150)

Note: Sound levels are normalized to 33 feet (10 meters) from piles

Based on the underwater sound levels measured by the far-field hydrophone during vibratory pile driving and the maximum allowable time for vibratory pile driver each day (3 hours), it was estimated that up to 108 feet (33 meters) would be required for underwater sound levels to reach the Level A marine mammal threshold. Underwater sound levels are expected to reach Level B marine mammal thresholds 751 feet (229 meters) from the piles.

2.0 INTRODUCTION

This Report summarizes the results of airborne and underwater sound levels measured during the removal of timber piles and installation of 16-inch diameter piles with a vibratory pile driver. All measurements were conducted in February 2024.

The Marine Mammal Monitoring Plan for this Project specifies requirements for the number of measurement locations, signal processing, and reporting. This Report fulfills the Project's acoustic monitoring, signal processing, and reporting requirements.

The Project is in West Seattle, near the southwest portion of Elliott Bay in Seattle, Washington. The location of the Project is shown in Figure 1.

Figure 1 Project Location

3.0 NOMENCLATURE

Auditory response to sound is a complex process that occurs over a wide range of frequencies and intensities. Decibel levels, or “dB,” are a form of shorthand that compresses this broad range of intensities with a convenient, logarithmic scale.

Decibels are defined as the squared ratio of the sound pressure level (SPL) with a reference sound pressure. The reference pressure for airborne sound is 20 micropascals (μPa) and for underwater sound the reference pressure is 1 μPa. The use of 20 μPa in air is convenient because 1 dB re: 20 μPa correlates to the human threshold for hearing. It is important to note that because of these different decibel reference pressures and physical properties of water and air, airborne and underwater sound levels cannot be directly compared.

The following metrics are referenced in this Report:

- **Peak**

  The peak sound pressure level is the instantaneous absolute maximum pressure observed during a measured event. Peak pressure can be presented as a pressure or dB referenced to a standard pressure (20 μPa for airborne and 1 μPa for underwater).

- **Root Mean Square (RMS)**

  The RMS level is the square root of the average squared pressure over a given time. In hydroacoustics, the RMS level has been used by the National Marine Fisheries Service (NMFS) in criteria for assessing sound pressure impact on marine mammals.

- **Sound Exposure Level (SEL)**

  The SEL is the squared sound pressure integrated or summed over time, referenced to a standard pressure squared (20 μPa for airborne and 1 μPa for underwater), normalized to one second, and converted to decibels.

- **Cumulative Sound Exposure Level (cSEL)**

  The cSEL is the SEL accumulated over time. In this report cSEL is calculated by combining the single strike SEL values for each pile.

4.0 REGULATORY CRITERIA

Anticipated underwater sound levels 33 feet (10 meters) from pile activities are listed in the Waterfront Park Reconstruction Project Season 2 Marine Mammal Monitoring Plan, dated September 2023 (MMM Plan), and are shown in Table 3.

Table 3 Anticipated Underwater Sound Levels, RMS dB re: 1 μPa

Type	Method	Source Sound Level
Timber pile	Vibratory Removal	145
16-inch steel pipe pile	Vibratory Installation	158

The MMM Plan specifies the following acoustic monitoring and reporting requirements:

- Up to four days of acoustic monitoring will be conducted with the goal of collecting data from each type of pile related activity.
- Measurements will be made with at least two hydrophones, and one microphone to record airborne sound levels. A direct line of acoustic transmission between the hydrophones and pile activities should be maintained, whenever possible.
- One hydrophone will be located 33 feet (10 meters) from the pile activities and the other hydrophone will be located approximately 3H, where H is the water depth at the pile. Due to site access and safety constraints, measurement distances may exceed 10 meters (33 feet) from the piles. Both hydrophones will be deployed near mid-water depth, but at least 3 feet (1 meter) below the surface and 3 feet (1 meter) above the seafloor.
- Results from measurements not made at 10 meters (33 feet) from the piles will be normalized to 10 meters (33 feet) using the Practical Spreading Model.
- Record sound levels continuously throughout pile activities during the monitoring period.
- Prior to monitoring, water depth will be measured to ensure the hydrophones will not drag on the bottom during tidal changes.
- Configure the hydrophones, signal conditioning, and recording equipment to acquire data without clipping.
- Underwater data will be post processed to calculate the range, logarithmic average, median, and standard deviation of peak, RMS, and SEL sound levels. The 24-hour cSEL for each day of pile driving will be reported and the frequency spectrum will be provided for each functional hearing group. All underwater source levels will be standardized to a reference distance of 33 feet (10 meters).
- Post analysis of airborne sound levels will include the range and average of the unweighted RMS sound levels for each recorded pile. The average values will be used to determine the extent of the airborne isopleths relative to species specific criteria. The airborne frequency spectrum will be provided from 20 Hz to 20 kHz and all airborne source levels will be normalized to 50 feet (15 meters).
- Perform acoustic monitoring using a standardized methodology that will facilitate comparisons with other studies.

5.0 PILE AND PILE DRIVING EQUIPMENT INFORMATION

Pile removal was completed using an ICE Model 416L Hydraulic Vibratory Driver and Extractor. The ICE 416L operates at a maximum frequency of 1,700 VPM, a maximum line pull of 40 tons (355 kilonewtons) and has a suspended weight of 11,500 pounds (5,215 kilograms).

Piles were driven with an APE Model 200 Vibratory Pile Driver and Extractor. The APE 200 has a maximum driving frequency of 1,650 VPM with a maximum driving force of 170 tons (1,513 kilonewtons) and weighs 12,760 pounds (5,788 kilograms).

Photos of the ICE 416L and APE 200 are shown in Figure 2 and Figure 3, and cut sheets for both units can be found in the Appendix.

Figure 2 ICE 416L

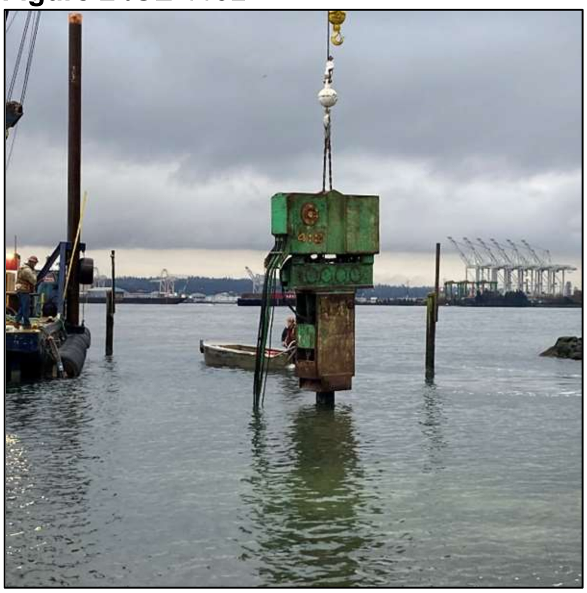
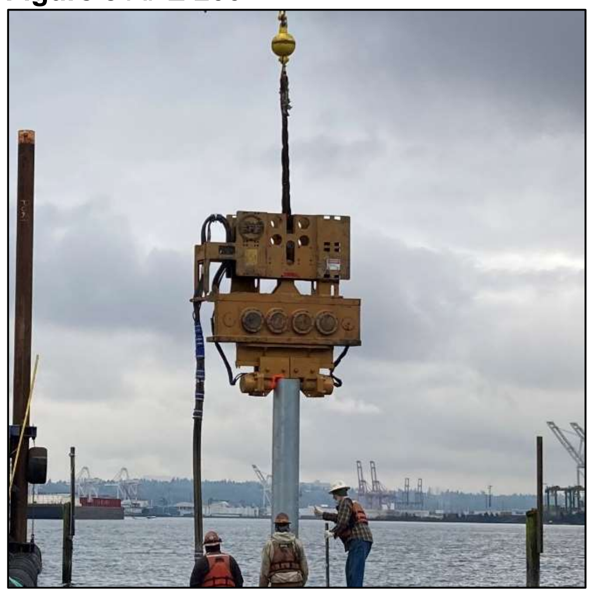


Figure 3 APE 200



Piles were driven through holes cut in the concrete boat ramp. The substrate the piles were driven into was soft native material. Debris and driving obstructions were located approximately 10 feet (3 meters) below the surface.

Figure 4 Seafloor at Don Armeni Boat Ramp

The extracted piles were timber piles embedded approximately 10 feet into the substrate. Installed piles were 16-inch diameter steel pipe piles with a 5/8-inch wall thickness. The piles driven during the acoustic monitoring were approximately 48 to 57 feet (15 to 17 meters) in length and were driven approximately 25 feet (7.6 meters) into the substrate. A summary of the piles that were removed and installed during the acoustic monitoring are shown in Table 4. This summary includes the date of the pile activities, approximate water depth at the pile, approximate embedment depth, and the duration of the pile extraction or pile drive.

Table 4 Summary of Pile Activities

Pile ID	Date	Pile Activity	Water Depth, Feet (Meters)	Embedment, Feet (Meters)	Duration, Seconds
Timber-1	2/5/2024	Removal	23 (7)	10 (3.3)	50
Timber-2			17 (5)		50
Timber-3			14 (4)		140
Timber-4	2/6/2024		6 (2)		150
Pile-1		Installation	9 (3)	25 (7.6)	5,370
Pile-2	2/7/2024		10 (3)		680
Pile-3			13 (4)		2,070
Pile-4			17 (5)		680
Pile-5			21 (6)		1,970

1. Embedment depth is based on information shown in the Project's design drawings.
2. Duration of pile drive is based on the hydroacoustic analysis and may differ from information in the pile logs.

6.0 MEASUREMENT METHODOLOGY

The measurement equipment and methodology, including the instrumentation used to make the measurements, measurement locations and deployment methods, are discussed in Section 6.1 and Section 6.2.

6.1 Measurement Equipment

The hydroacoustic and airborne monitoring equipment used during the measurements is identified in Table 5 and

Table 6. Calibration tones were recorded before and after each day of monitoring for verification of calibration factors used during post-processing. Hydrophones were calibrated using the G.R.A.S. pistonphone and the microphone was calibrated with the Larson Davis CAL200 acoustic calibrator.

Table 5 Hydroacoustic Monitoring Equipment

Make and Model	Quantity	Description	Serial Number
Brüel & Kjaer Type 2250	1	Sound Level Analyzer	3006756
Reson TC-4013	2	Hydrophone	2513032
			2018079
Brüel & Kjaer Type 2647-A	1	Charge Converter (1 mV/pC)	2582112
PCB 422E53	1	Charge Converter (1 mV/pC)	65399
G.R.A.S. Type 42AC	1	Pistonphone	201835
NTi Audio ICP Adaptor	1	ICP Power Supply	-
Tascam DR-100MKIII	1	Digital Audio Recorder	1690316

Table 6 Airborne Monitoring Equipment

Make and Model	Quantity	Description	Serial Number
Svantek 979	1	Sound Level Analyzer	46177
PCB 426E01	1	Preamplifier	53673
G.R.A.S. 40 AE	1	Microphone	258193
Larson Davis CAL200	1	Acoustic Calibrator	16828

Underwater sound levels were measured concurrently at two locations during pile driving and airborne sound levels were measured at one location. The equipment used at each location were as follows:

- Equipment used to measure sound levels at 33 feet (10 meters) from pile activities (near-field location) included a Reson TC-4013 hydrophone connected to a Brüel & Kjaer Type 2647-A charge converter. The charge converter was connected to the Brüel & Kjaer Type 2250 Sound Level Analyzer, which allowed for real-time approximations of peak sound pressure levels and cSEL while the measurements were being performed. The Brüel & Kjaer Type 2250 Sound Level Analyzer recorded the signal as a WAV file.
- Equipment used to measure sound levels at a distance of at least 3H from the pile activities (far-field location) consisted of a Reson TC-4013 hydrophone connected to the PCB 422E53 charge converter. The charge converter was powered by the NTi Audio ICP Adaptor. The signal was recorded by the Tascam DR-100MKIII digital audio recorder as a WAV file.
- Airborne sound levels were measured using the Svantek 979 sound level analyzer, which meets the requirements of an ANSI Type 1 sound level analyzer. The airborne equipment recorded a WAV file, as well as logged 1-second broadband unweighted RMS sound levels. 1/3 octave band RMS sound levels were also recorded at 1-second intervals.

The Brüel & Kjaer Type 2250 Sound Level Analyzer, Tascam DR-100MKIII, and Svantek 979 all recorded the signals as WAV files at a sample rate of 48,000 samples per second for subsequent signal analysis.

Photographs of the monitoring equipment are provided in Figure 5 through Figure 7.

Figure 5 Near-Field

Figure 6 Far-Field

Figure 7 Airborne

6.2 Measurements

Two hydrophones were used to measure underwater sound levels from in-water pile activities. The near-field hydrophone was located at mid-water depth as close to 33 feet (10 meters) from the pile being driven as feasible. The far-field hydrophone was located 3 feet (1 meter) below the surface. Both hydrophones maintained an unobstructed acoustic transmission path to the piles during all pile activities.

The near-field hydrophone was suspended from the north floating dock. Deploying the hydrophone from the north dock allowed for sound levels to be measured approximately 33 feet (10 meters) from the piles being installed for the north dock replacement. However, prior to the measurements, the south floating dock was removed to allow for the removal of the timber piles. This prevented a similar deployment method to capture the piles installed for the south dock and limited access to areas near the south piles. Therefore, measurement distances to pile removal and installation of piles driven for the south floating dock were made at distances greater than 33 feet (10 meters) from the piles.

The far-field hydrophone was suspended 3 feet (1 meter) below a buoy, north of the north floating dock. This location was selected to be farther away than the near-field measurements and to not interfere with portions of the boat ramp still open to the public.

The microphone was located near the north concrete abutment and was approximately 5 feet (1.5 meters) above the ground and at least 6 feet (1.8 meters) from any acoustically reflective surfaces. The microphone was not located on the north dock to allow unobstructed access to the dock by the public. A direct acoustic transmission path was maintained between the microphone and the pile activities throughout the measurements.

The distances between the monitoring locations and the pile activities were measured using a laser distance measure or calculated using Project drawings and GPS coordinates of the monitoring equipment. Water depths at the hydrophone locations were measured prior to deploying the hydrophones, and tidal information obtained from NOAA Station #9447130 was used to track tidal changes throughout the measurements. Additional information about the hydrophone locations, including the water depth at the hydrophones, depth of the hydrophones, and distances from hydrophones to piles are provided in Table 7.

Table 7 Hydrophone Location Summary, Feet (Meters)

Pile ID	Water Depth		Hydrophone Depth		Distance to Pile	
	Near	Far	Near	Far	Near	Far
Timber-1	16 (4.9)	11 (3.4)	8 (2.4)	3 (0.9)	20 (6.1)	36 (11)
Timber-2	16 (4.9)	11 (3.4)	8 (2.4)	3 (0.9)	18 (5.5)	33 (10.1)
Timber-3	16 (4.9)	11 (3.4)	8 (2.4)	3 (0.9)	18 (5.5)	31 (9.4)
Timber-4	12 (3.7)	7 (2.1)	6 (1.8)	3 (0.9)	22 (6.7)	31 (9.4)
Pile-1	13 (4.0)	8 (2.4)	6 (1.8)	3 (0.9)	23 (7.0)	31 (9.4)
Pile-2	14 (4.3)	9 (2.7)	8 (2.4)	3 (0.9)	10 (3.0)	13 (4.0)
Pile-3	9 (2.7)	7 (2.1)	6 (1.8)	3 (0.9)	10 (3.0)	18 (5.5)
Pile-4	16 (4.9)	11 (3.4)	8 (2.4)	3 (0.9)	18 (5.5)	33 (10.1)
Pile-5	16 (4.9)	11 (3.4)	8 (2.4)	3 (0.9)	7 (2.1)	22 (6.7)

Figures illustrating the pile and measurement locations during pile removal and installation are provided in Figure 8 and Figure 9.

Figure 8 Pile Removal and Measurement Locations

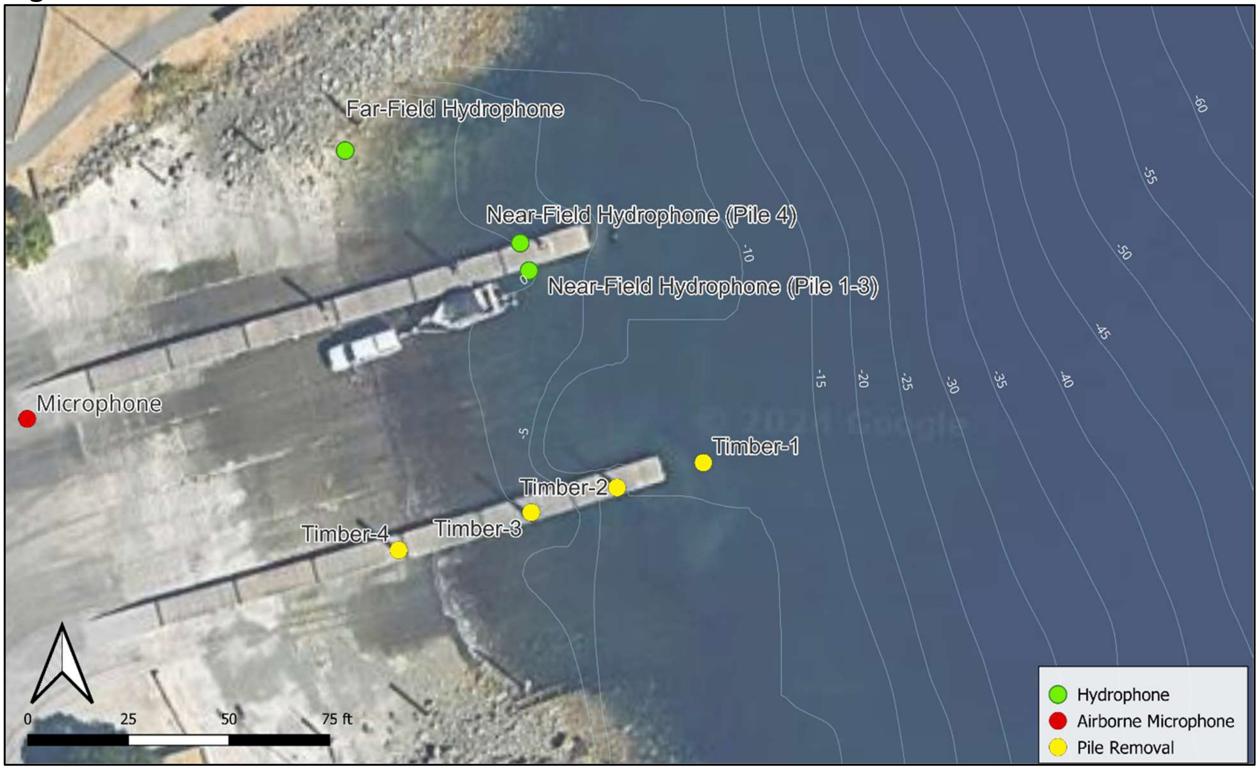
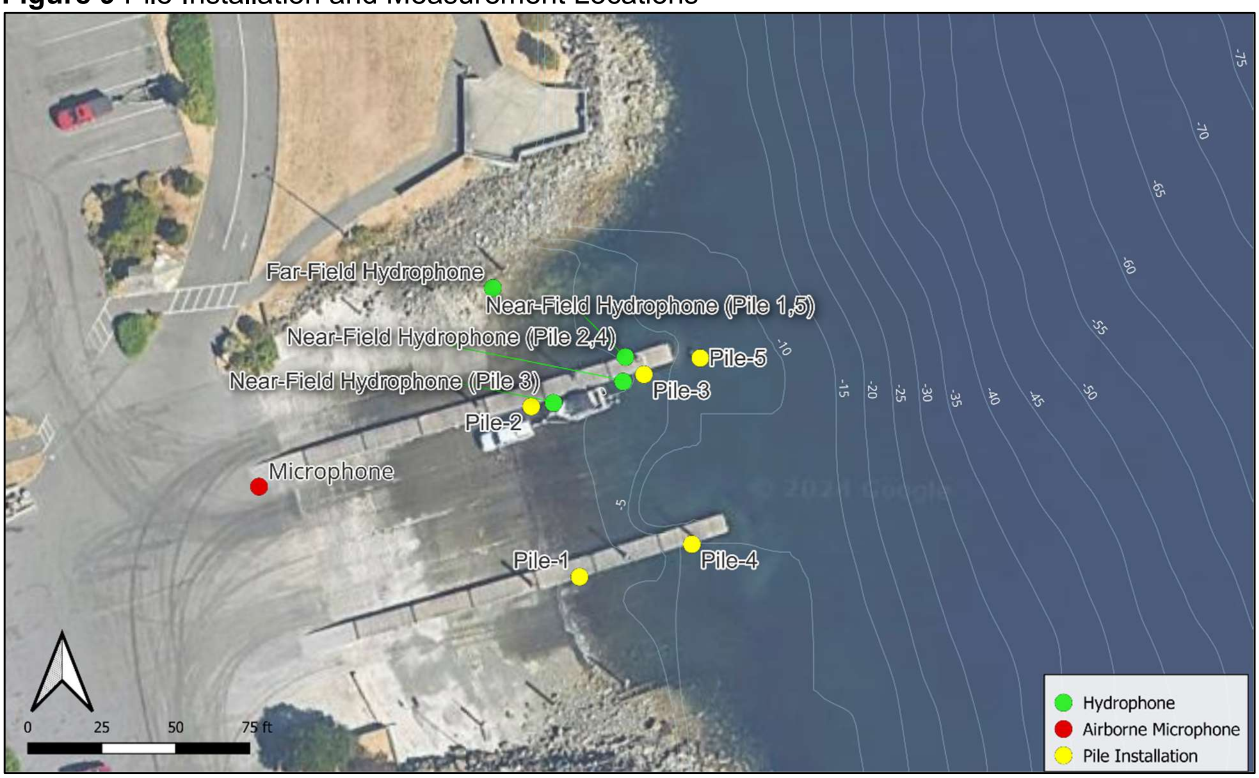


Figure 9 Pile Installation and Measurement Locations



7.0 ANALYSIS AND RESULTS

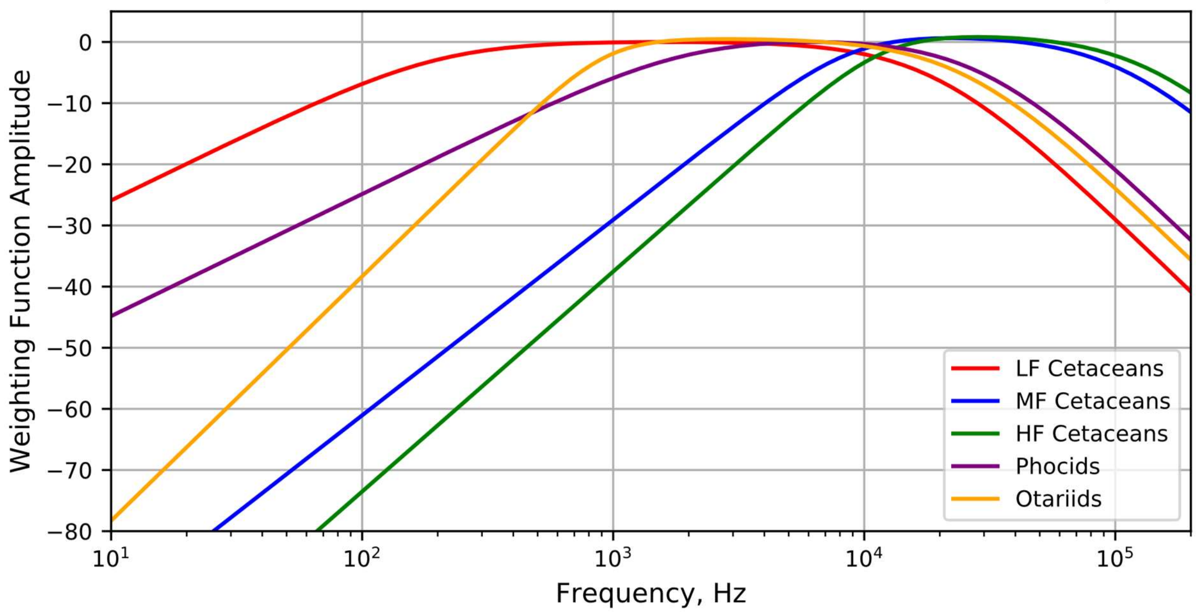
During post-processing, the hydroacoustic data were frequency-weighted for each of the marine mammal hearing groups defined in the NOAA technical guidance document titled "Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing" dated April 2018. This Technical Guidance divides marine mammals into five hearing groups, as summarized in Table 8.

Table 8 Marine Mammal Hearing Groups

Hearing Group	Generalized Hearing Frequency Range
Low-frequency (LF) cetaceans (baleen whales)	7 Hz – 35 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whaled, bottlenose whales)	150 Hz – 160 kHz
High-frequency (HF) cetaceans (true porpoise, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger & L. australis*)	275 Hz – 160 kHz
Phocid pinnipeds (PW) (underwater) (true seals)	50 Hz – 86 kHz
Otariid pinnipeds (OW) (underwater) (sea lions and fur seals)	60 Hz -39 kHz

The auditory weighting functions for each marine mammal hearing group are illustrated in Figure 10.

Figure 10 Auditory Weighting Functions for Marine Mammal Hearing Groups, dB re: 1 μPa



Underwater sound levels measured by the hydrophones were normalized to 33 feet (10 meters) from pile driving activities using the Practical Spreading Model. For additional information on the Practical Spreading Model please see Section 8.0 of this Report.

Hydroacoustic data were analyzed to determine the range, mean, median, and standard deviation of the peak, RMS, and SEL for each pile drive. Standard deviation and median sound levels were calculated from decibel levels and mean sound levels were calculated from sound pressure in pascals. The RMS sound levels and SEL values were calculated over 10-second periods from unweighted data and for each marine mammal hearing group. Peak sound levels were calculated only from unweighted data. The cSEL for each pile were calculated by combining the SEL values measured over the duration of each pile drive. The resulting cSEL from each pile were then combined to produce a daily cSEL. Periods when pile activities were not occurring were excluded from the analysis.

Reported airborne sound levels were normalized to 50 feet (15 meters). Weighting functions were not applied to the airborne data during post-processing.

7.1 Timber Pile Removal

Underwater and airborne sound levels were measured on February 5 and February 6, 2024, during vibratory removal of four timber piles with an ICE Model 416L Hydraulic Vibratory Driver and Extractor. An unobstructed acoustical transmission path between the piles and sensors was maintained during all removal activities.

The ranges, means, and medians of underwater sound levels measured by both hydrophones during timber pile removal are shown in Table 9. Airborne RMS sound levels calculated 50 feet (15 meters) from pile removal activities ranged from 83 to 103 dB re: 20 μPa and the median RMS airborne sound level was 92 dB re: 20 μPa. Summaries of the broadband and 1/3 octave band airborne and underwater sound levels, and the unweighted underwater frequency spectrum from each pile are provided in the Appendix.

Table 9 Underwater Sound Levels during Pile Removal, dB re: 1 μPa

Hearing Group	Peak				RMS				SEL			
	Max	Min	Mean	Med	Max	Min	Mean	Med	Max	Min	Mean	Med
Near-Field Hydrophone												
Unweighted	177	153	169	167	164	134	156	149	174	144	166	159
LF Cetacean					144	123	137	132	154	133	147	142
MF Cetacean					158	129	150	142	168	139	160	152
HF Cetacean					159	129	150	143	169	139	160	153
PW					148	123	140	135	158	133	150	145
OW					145	121	138	133	155	131	148	143
Far-Field Hydrophone												
Unweighted	178	147	165	156	153	132	145	140	163	142	155	150
LF Cetacean					140	122	131	129	150	132	141	139
MF Cetacean					147	126	139	134	157	136	149	144
HF Cetacean					148	127	140	134	158	137	150	144
PW					141	122	132	129	151	132	142	139
OW					141	122	131	128	151	132	141	138

Note: All sound levels are normalized to 33 feet (10 meters) from the piles.

The daily cSEL measured by the near-field hydrophone are shown in Table 10. In addition to the measured daily cSEL, data collected by the far-field hydrophone were used to estimate what the daily cSEL values would be if piles were extracted for the maximum allowable extraction times per day, this is discussed further in Section 8.0.

Table 10 Measured Daily cSEL during Vibratory Pile Removal, dB re: 1 μPa

Hearing Group	2/5/2024	2/6/2024
Unweighted	181	173
Low-frequency (LF) cetaceans	162	155
Mid-frequency (MF) cetaceans	175	167
High-frequency (HF) cetaceans	176	168
Phocid pinnipeds (PW)	165	158
Otariid pinnipeds (OW)	163	156

Note: Sound levels from the near-field hydrophone normalized to 33 feet (10 meters) from the piles.

7.2 Vibratory Pile Driving

Sound levels were measured from vibratory pile driving with an APE Model 200 Vibratory Pile Driver on February 6 and February 7, 2024. An unobstructed acoustic transmission path between the sensors and piles was maintained throughout each pile drive. Due to driving obstructions, the piles were often driven, removed, and redriven. The removal and installation were both completed while the vibratory hammer was operating, and both are included in this analysis.

The ranges, means, and medians of underwater sound levels measured by the hydrophones during vibratory pile driving are shown in Table 11. Airborne RMS sound levels calculated 50 feet (15 meter) from vibratory pile driving ranged from 83 to 106 dB re: 20 μPa and the median RMS sound level was 93 dB re: 20 μPa. Broadband and 1/3 octave band airborne and underwater sound level summaries, and the unweighted underwater frequency spectrum from each pile are provided in the Appendix.

Table 11 Underwater Sound Levels during Vibratory Pile Driving, dB re: 1 μPa

Hearing Group	Peak				RMS				SEL			
	Max	Min	Mean	Med	Max	Min	Mean	Med	Max	Min	Mean	Med
Near-Field Hydrophone												
Unweighted	193	152	177	163	166	125	154	147	176	135	164	157
LF Cetacean					161	116	148	141	171	126	158	151
MF Cetacean					164	120	151	142	174	130	161	152
HF Cetacean					163	120	151	142	173	130	161	152
PW					162	116	149	139	172	126	159	149
OW					161	116	149	140	171	126	159	150
Far-Field Hydrophone												
Unweighted	192	144	177	161	168	125	155	146	178	135	165	156
LF Cetacean					162	120	149	140	172	130	159	150
MF Cetacean					165	121	151	140	175	131	161	150
HF Cetacean					164	121	151	140	174	131	161	150
PW					163	120	150	138	173	130	160	148
OW					163	120	150	139	173	130	160	149

Note: All sound levels are normalized to 33 feet (10 meters) from the piles.

The daily cSEL measured by the near-field hydrophone are shown in Table 12. In addition to the measured daily cSEL, data collected by the far-field hydrophone were used to estimate what the daily cSEL would be if the piles were driven for the maximum allowable driving times per day, this is discussed further in Section 8.0.

Table 12 Measured Daily cSEL during Vibratory Pile Driving, dB re: 1 μPa

Hearing Group	2/6/2024	2/7/2024
Unweighted	184	194
Low-frequency (LF) cetaceans	178	188
Mid-frequency (MF) cetaceans	178	191
High-frequency (HF) cetaceans	179	191
Phocid pinnipeds (PW)	176	189
Otariid pinnipeds (OW)	177	189

Note: Sound levels from the near-field hydrophone normalized to 33 feet (10 meters) from the piles.

8.0 DISTANCE TO MARINE MAMMAL DISTURBANCE AND INJURY THRESHOLDS

Data collected during pile driving were used to estimate the distance required for underwater sound produced by pile driving to dissipate to the injury threshold (Level A), disturbance threshold (Level B), and background sound level.

In April 2018, NOAA issued updated technical guidance for determining the effects of underwater sound on marine mammals titled “Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing”. The Technical Guidance lists injury criteria from non-impulsive sounds, such as vibratory pile driving and extraction. These criteria are based on 24-hour cSEL values, which are frequency weighted for each marine mammal hearing group. Injury thresholds provided in the Technical Guidance are summarized in Table 13.

Table 13 Non-Impulsive Injury Thresholds (Level A), dB re: 1 μPa

Hearing Group	Daily cSEL
Low-frequency (LF) cetaceans	199
Mid-frequency (MF) cetaceans	198
High-frequency (HF) cetaceans	173
Phocid pinnipeds (PW) (underwater)	201
Otariid pinnipeds (OW) (underwater)	219

Source: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, April 2018

Marine mammal disturbance thresholds (Level B) from underwater sound are based on RMS sound levels from previous guidance provided by the NMFS. Disturbance thresholds from vibratory pile driving and removal are shown in Table 14.

Table 14 Disturbance Thresholds (Level B), RMS dB re: 1 μPa

Marine Mammal	Vibratory Pile Driving
Cetaceans	120
Pinnipeds	

Source: National Marine Fisheries Service

The distances for underwater sound to dissipate to the marine mammal thresholds shown in Table 13 and Table 14, and background sound levels were calculated using the “practical spreading model” currently used by NOAA. The practical spreading formula is provided below.

$$\mathrm{SPL_{D2}} = \mathrm{SPL_{D1}} + \beta * \log_{10}\left(\frac{\mathrm{D_1}}{\mathrm{D_2}}\right)$$

Where $\mathrm{SPL_{D1}}$ is the sound pressure measured at distance, D_1 and $\mathrm{SPL_{D2}}$ is the estimated sound pressure at distance, D_2. β is the attenuation factor resulting from acoustic spreading over distance. The California Department of Transportation (Caltrans) reported in the “Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish” dated November 2015, that β can range between 5 and 30 depending upon site specific conditions such as water depth, pile type, pile length, and the substrate the pile is driven into. Currently, NOAA uses the practical spreading model with β equaling 15, which results in a 4.5 dB reduction in underwater sound levels for each doubling of distance.

The formula provided above was also used to calculate the distances for airborne noise to reach the disturbance levels for harbor seals and other pinnipeds, which is discussed later in the section. In the case of airborne noise, β is equal to 20, which is consistent with information provided in the WSDOT document “Biological Assessment Preparation for Transportation Projects-Advanced Training Manual-Version 2020” for sound propagation from a point source over hard soil.

The distances required for underwater noise to dissipate to below the marine mammal thresholds and background sound levels are estimated by solving the practical spreading formula for D_2, resulting in the following:

$$\mathrm{D_2} = \mathrm{D_1} * 10^{\left(\frac{\mathrm{SPL_{D1}} - \mathrm{SPL_{D2}}}{15}\right)}$$

To estimate the distance required for underwater noise from pile driving to dissipate to the marine mammal thresholds and background sound levels, data collected by the far-field hydrophone were normalized to 33 feet (10 meters), which allowed for comparison of measured sound levels. The data collected by the far-field hydrophone was used because it provides a more accurate representation of sound levels at greater distances. After normalizing the sound levels, the median RMS and SEL were used to calculate the distance to the marine mammal thresholds and background sound levels. Instead of using the measured cSEL, the median SEL measured by the far-field hydrophone was used to calculate the daily cSEL. The measured cSEL was not used because the maximum allowable pile removal and vibratory pile driving times each day (3 hours per day for vibratory pile driving and 2 hours 40 minutes for removal) were not reached during the acoustic monitoring and therefore, the measured cSEL would not represent the maximum distance required for underwater sound levels to dissipate to the threshold criteria.

The resulting distances for underwater sound from pile removal and vibratory pile driving to dissipate to the marine mammal thresholds are shown in Table 15 and Table 16.

Table 15 Distance to Marine Mammal Thresholds during Vibratory Pile Driving, dB re: 1 μPa

Hearing Group	Measured Sound Level, dB		Marine Mammal Threshold, dB		Distance to Threshold, Feet (Meters)	
	cSEL[1]	RMS	Level A, cSEL	Level B, RMS	Level A	Level B
LF Cetaceans	186	146	199	120	2 (0.6)	710 (216)
MF Cetaceans	180	140	198		2 (0.7)	708 (216)
HF Cetaceans	180	140	173		108 (32.8)	751 (229)
Pinnipeds (Phocids)	181	140	201		1 (0.3)	510 (155)
Pinnipeds (Otariids)	178	138	219		0.1 (0.02)	610 (186)

1. Daily cSEL was calculated from the median SEL measured by the far-field hydrophone and maximum allowable duration of vibratory pile driving.

Table 16 Distance to Marine Mammal Thresholds during Pile Removal, dB re: 1 μPa

Hearing Group	Measured Sound Level, dB		Marine Mammal Threshold, dB		Distance to Threshold, Feet (Meters)	
	cSEL[1]	RMS	Level A, cSEL	Level B, RMS	Level A	Level B
LF Cetaceans	180	140	199	120	0.3 (0.1)	137 (42)
MF Cetaceans	169	129	198		0.8 (0.2)	270 (82)
HF Cetaceans	174	134	173		39 (12.0)	297 (91)
Pinnipeds (Phocids)	174	134	201		0.2 (0.1)	126 (38)
Pinnipeds (Otariids)	169	129	219		0.01 (0.004)	118 (36)

1. Daily cSEL was calculated from the median SEL measured by the far-field hydrophone and maximum allowable duration of vibratory pile removal.

Disturbance thresholds from airborne noise are based on RMS sound levels and are provided in Table 17.

Table 17 Airborne Disturbance Thresholds, RMS dB re: 20 μPa

Marine Mammal	Disturbance Threshold (Level B)
Harbor Seal	90
Other Pinnipeds	100

The median measured 1-second RMS sound level was used to calculate the distances for airborne sound to reach disturbance thresholds for harbor seals and other pinnipeds, these distances are shown in Table 18.

Table 18 Airborne Marine Mammal Threshold Distances, dB re: 20 μPa

Pile Activity	Disturbance Threshold, dB		Measured RMS Sound Level, dB	Distance to Threshold, Feet (Meters)	
	Harbor Seal	Other Pinnipeds		Harbor Seal	Other Pinnipeds
Vibratory Removal	90	100	92	63 (19)	20 (6)
Vibratory Pile Driving			93	71 (22)	22 (7)

As shown in Table 16, up to 39 feet (12 meters) may be needed for sounds from pile removal to dissipate to the injury thresholds for high-frequency cetaceans and 297 feet (91 meters) may be required to reach the disturbance thresholds. Up to 108 feet (33 meters) are expected to be required for underwater sound levels generated by vibratory pile installation to reach the injury thresholds and 751 feet (229 meters) may be needed to reach injury thresholds.

The distances needed for sound to dissipate to below background sound levels were calculated using the median daytime background sound levels measured for each marine mammal hearing group between March 19 and March 22, 2018, during Season 1 of the Pier 62 Project. Pier 62 is located across Elliott Bay, approximately 2 miles (3.2 kilometers) northeast of the Don Armeni Boat Ramp. Background sound levels and distances to reach these background sound levels are shown in Table 19.

Table 19 Distances to Background Sound Levels, dB re: 1 μPa

Hearing Group	Background RMS Sound Level, dB	Median RMS, dB		Distance to Background, Feet (Meters)	
		Pile Removal	Vibratory Pile Driving	Pile Removal	Vibratory Pile Driving
LF Cetaceans	118	140	146	186 (57)	965 (294)
MF Cetaceans	121	129	140	232 (71)	608 (185)
HF Cetaceans	121	134	140	255 (78)	644 (196)
Phocids	115	134	140	271 (83)	1,098 (335)
Otariids	115	129	138	254 (77)	1,314 (401)

It is estimated that up to 1,314 feet (401 meters) may be needed for underwater RMS sound levels from vibratory pile driving to dissipate to below background sound levels and up to 271 feet (83 meters) may be required for vibratory removal.

9.0 MARINE MAMMAL MONITORING

Monitors observed California sea lion, harbor seal, and harbor porpoise within the monitoring zone during work activities. These animals did not exhibit any changes in behavior associated with pile installation activities. Details of marine mammal monitoring are presented in a separate memorandum entitled “Waterfront Park Reconstruction Project Season 2 and Don Armeni Boat Ramp Project Marine Mammal Monitoring Report”.

10.0 REFERENCES

Anchor QEA. “Waterfront Park Reconstruction Project Season 2 Marine Mammal Monitoring Plan.” September 2023.

California Department of Transportation. “Hydroacoustic Effects of Pile Driving on Fish.” November 2015.

NMFS Northwest Region and Northwest Fisheries Science Center. “Guidance Document: Data Collection Methods to Characterize Impact and Vibratory Pile Driving Source Levels Relevant to Marine Mammals.” January 31, 2012.

NOAA. “Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts.” April 2018.

Washington State Department of Transportation. “Biological Assessment Preparation for Transportation Projects-Advanced Training Manual-August 2020.”

APPENDIX

Table of Contents

1.0 VIBRATORY PILE REMOVAL

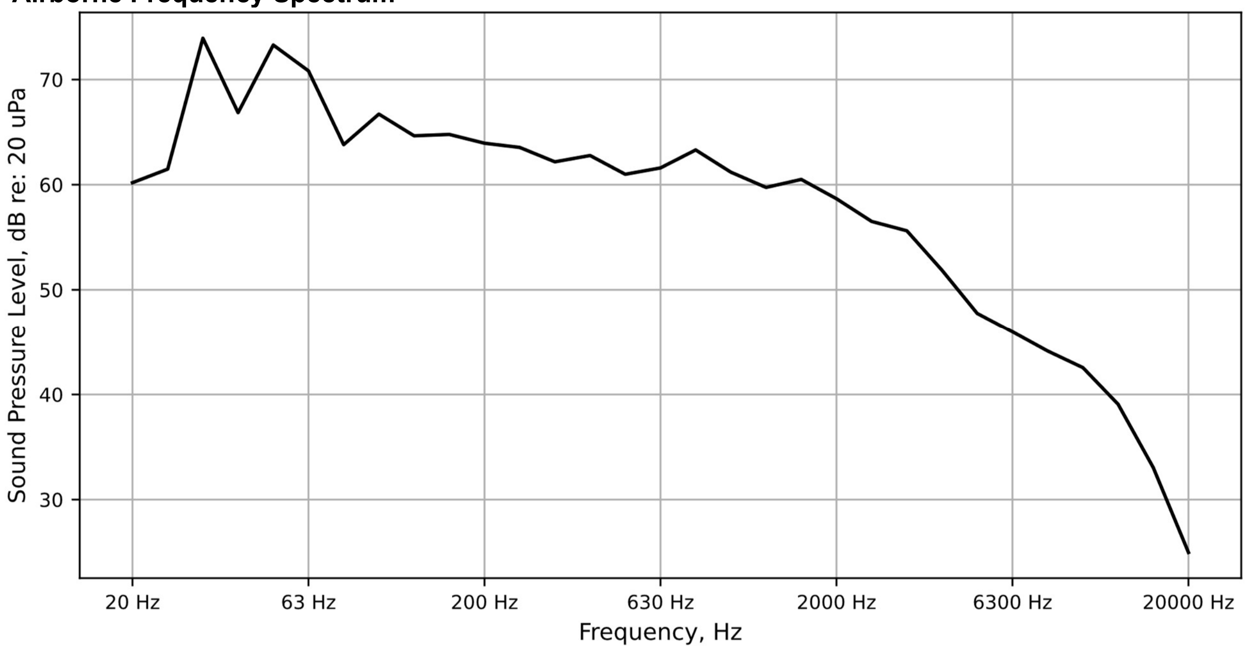
REMOVAL – 1

February 5, 2024

Airborne Sound Levels, dB re: 20 μPa

Median	Minimum	Maximum
93	90	103

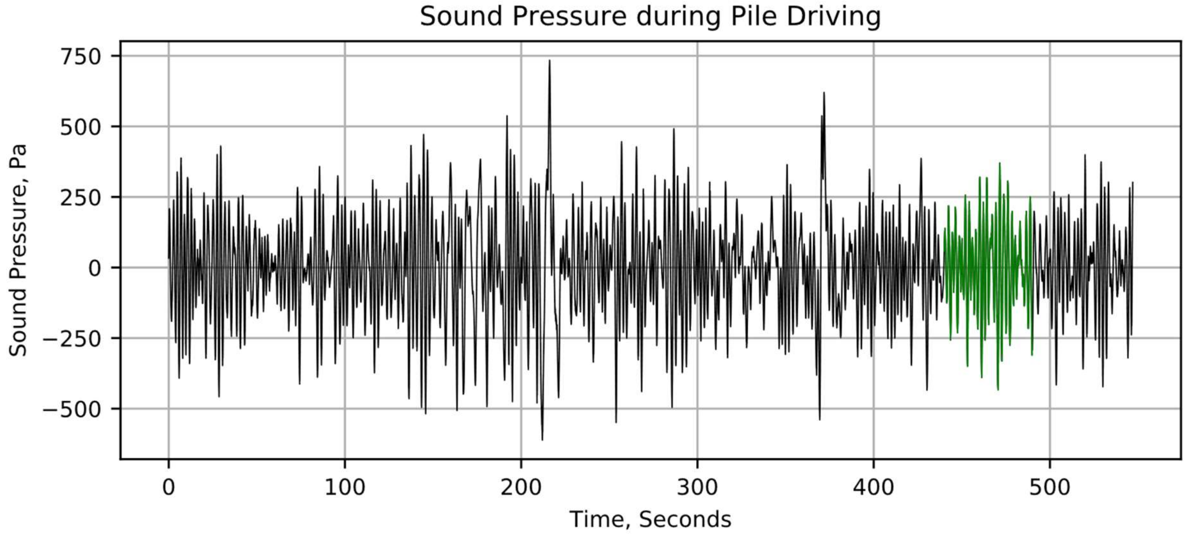
Airborne Frequency Spectrum

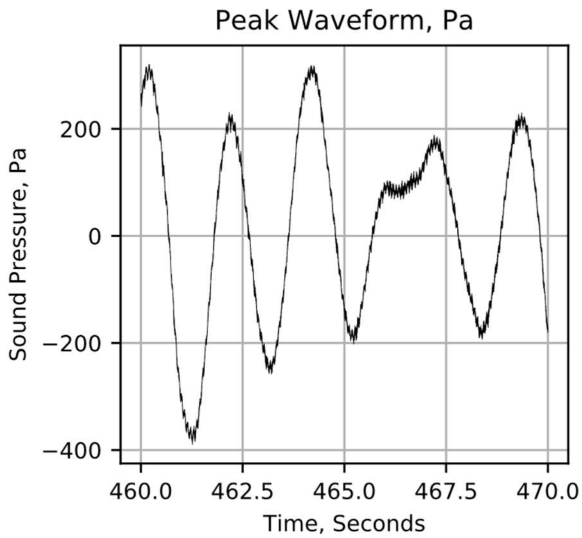


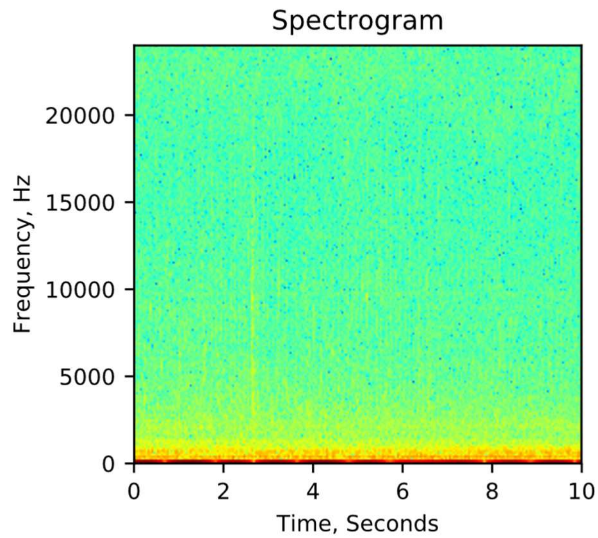
Underwater Sound Levels, dB re: 1 μPa

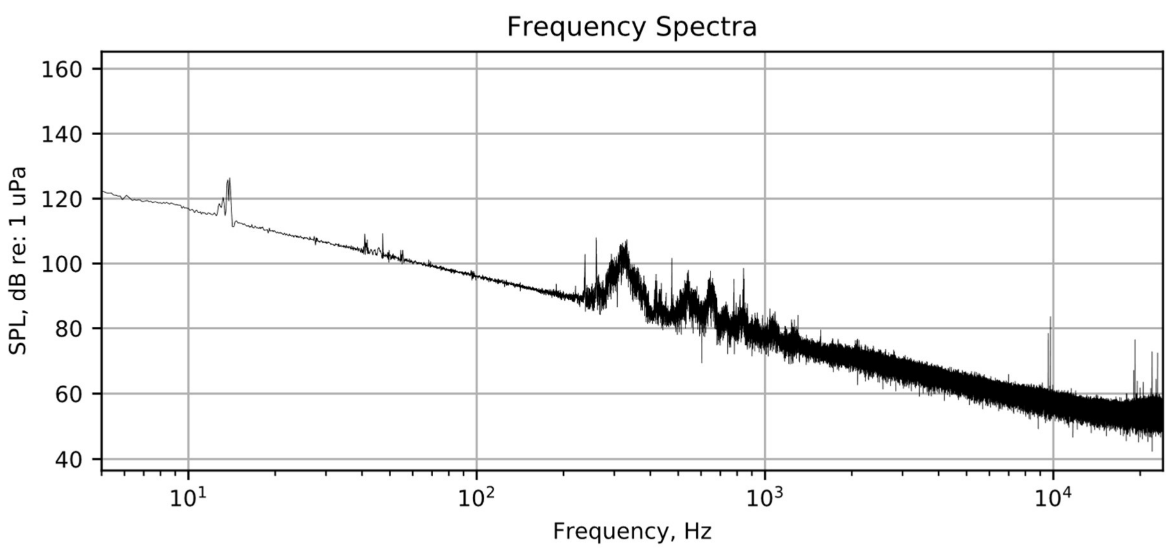
Frequency Range	Peak					RMS					SEL					cSEL
	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	
Near-Field Hydrophone																
Unweighted	173	159	5.5	168	161	145	136	3.2	142	142	155	146	3.2	152	152	159
LF Cetacean						132	123	3.2	129	129	142	133	3.2	139	139	146
MF Cetacean						139	130	3.1	136	136	149	140	3.1	146	146	153
HF Cetacean						139	130	3.1	136	137	149	140	3.1	146	147	153
PW						130	123	2.8	127	127	140	133	2.8	137	137	144
OW						128	121	2.6	125	125	138	131	2.6	135	135	142
Far-Field Hydrophone																
Unweighted	159	150	2.8	156	155	138	133	1.7	136	136	148	143	1.7	146	146	153
LF Cetacean						129	124	1.6	127	127	139	134	1.6	137	137	144
MF Cetacean						132	127	1.5	130	130	142	137	1.5	140	140	147
HF Cetacean						132	128	1.6	131	131	142	138	1.6	141	141	148
PW						126	122	1.1	124	124	136	132	1.1	134	134	141
OW						125	122	1.0	124	124	135	132	1.0	134	134	141

Note: Measurement distances normalized to 33 feet (10 meters)


Sound Pressure during Pile Driving
Sound Pressure, Pa
750
500
250
0
−250
−500
0
100
200
300
400
500
Time, Seconds


Peak Waveform, Pa
Sound Pressure, Pa
200
0
−200
−400
460.0
462.5
465.0
467.5
470.0
Time, Seconds


Spectrogram
Frequency, Hz
20000
15000
10000
5000
0
0
2
4
6
8
10
Time, Seconds


Frequency Spectra
SPL, dB re: 1 uPa
160
140
120
100
80
60
40
10^1
10^2
10^3
10^4
Frequency, Hz

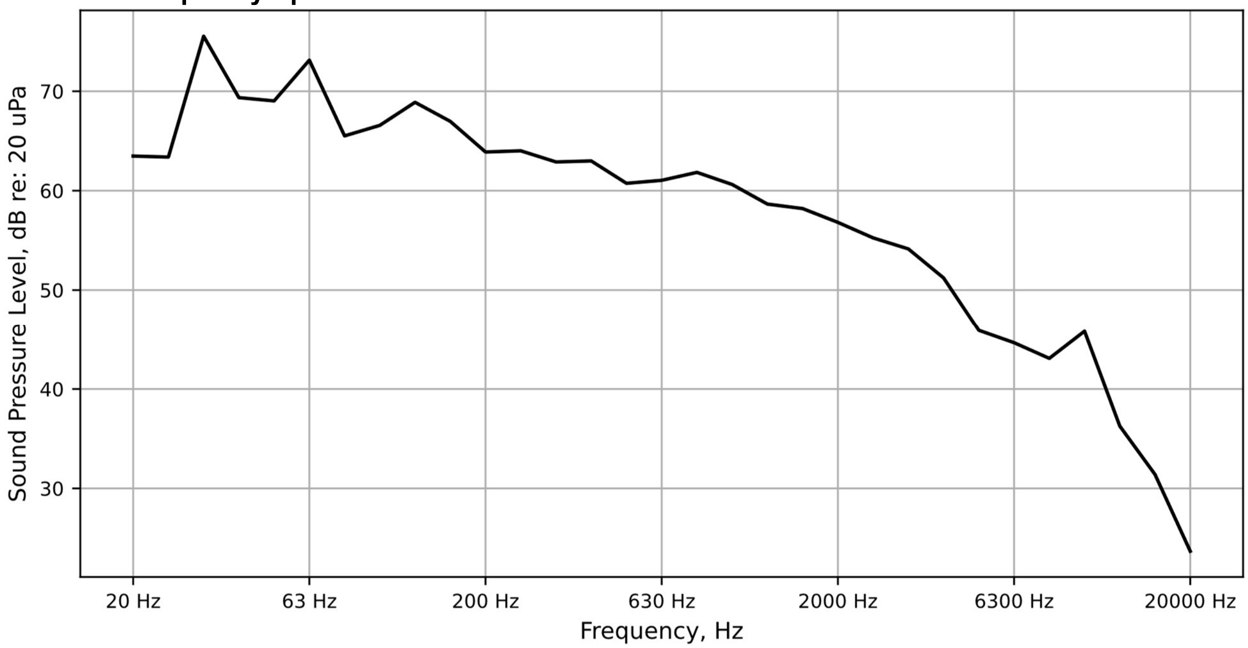
REMOVAL – 2

February 5, 2024

Airborne Sound Levels, dB re: 20 μPa

Median	Minimum	Maximum
92	89	98

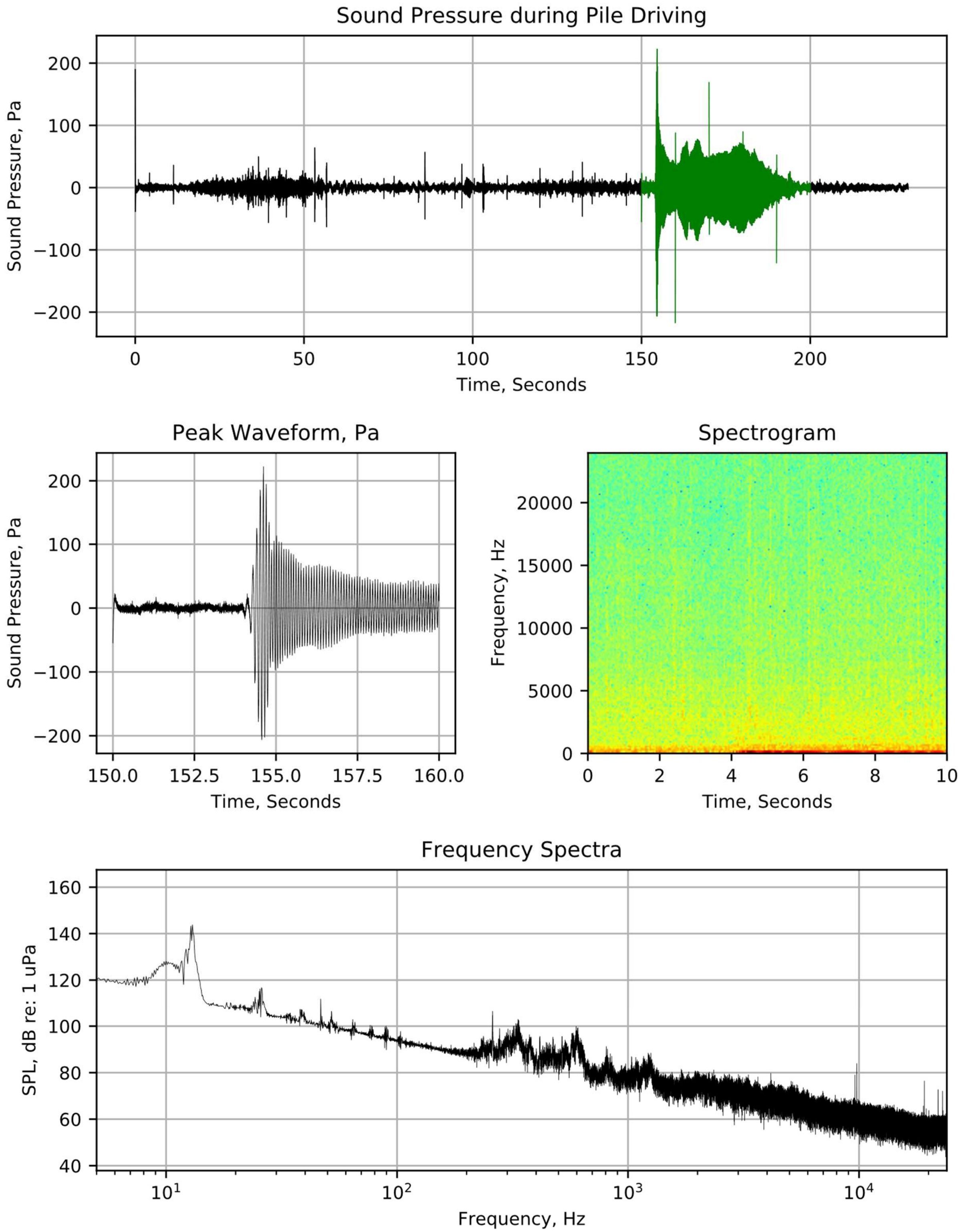
Airborne Frequency Spectrum



Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS					SEL					cSEL
	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	
Near-Field Hydrophone																
Unweighted	171	163	3.0	168	168	155	140	5.8	154	155	165	150	5.8	164	165	171
LF Cetacean						136	128	3.0	135	135	146	138	3.0	145	145	152
MF Cetacean						149	134	5.8	147	149	159	144	5.8	157	159	164
HF Cetacean						150	135	5.8	148	149	160	145	5.8	158	159	165
PW						139	126	5.1	138	139	149	136	5.1	148	149	155
OW						137	125	4.6	135	136	147	135	4.6	145	146	152
Far-Field Hydrophone																
Unweighted	158	153	2.3	157	157	144	136	3.0	141	142	154	146	3.0	151	152	158
LF Cetacean						129	126	1.1	127	127	139	136	1.1	137	137	144
MF Cetacean						138	130	2.9	135	136	148	140	2.9	145	146	152
HF Cetacean						138	130	3.0	136	137	148	140	3.0	146	147	153
PW						130	124	2.0	128	128	140	134	2.0	138	138	144
OW						129	124	1.6	127	127	139	134	1.6	137	137	144

Note: Measurement distances normalized to 33 feet (10 meters)


Sound Pressure during Pile Driving
Sound Pressure, Pa
Time, Seconds
Peak Waveform, Pa
Sound Pressure, Pa
Time, Seconds
Spectrogram
Frequency, Hz
Time, Seconds
Frequency Spectra
SPL, dB re: 1 uPa
Frequency, Hz

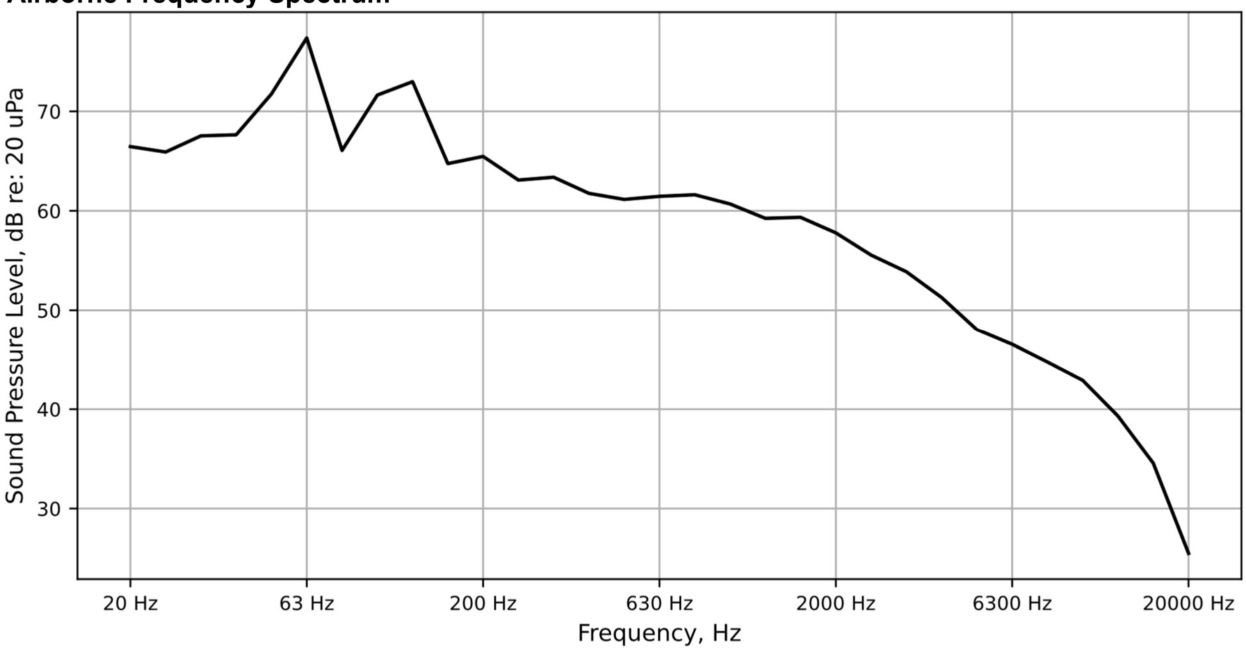
REMOVAL – 3

February 5, 2024

Airborne Sound Levels, dB re: 20 μPa

Median	Minimum	Maximum
94	87	100

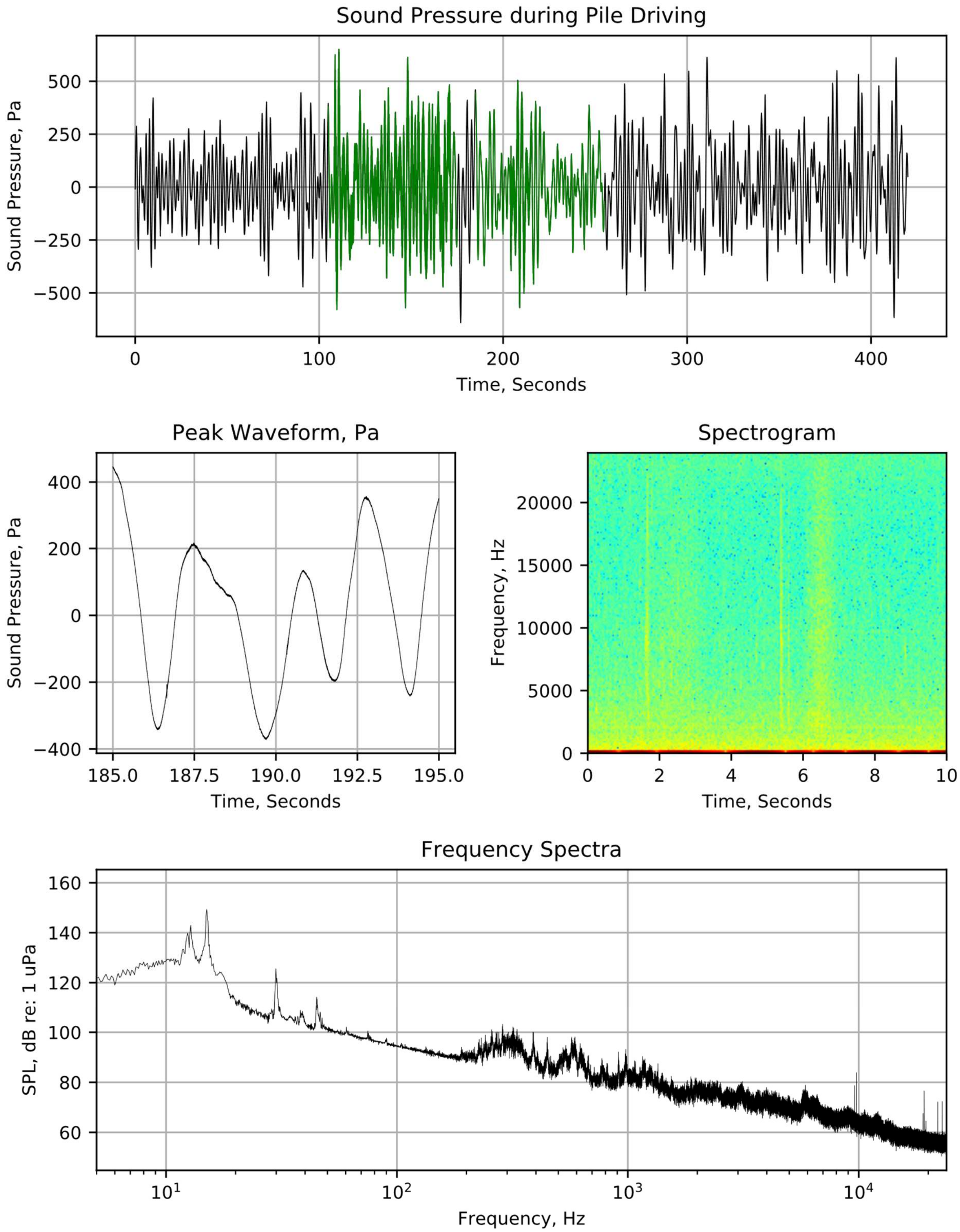
Airborne Frequency Spectrum



Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS					SEL					cSEL
	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	
Near-Field Hydrophone																
Unweighted	177	156	5.7	171	169	164	134	10.5	159	159	174	144	10.5	169	169	181
LF Cetacean						144	124	6.9	140	140	154	134	6.9	150	150	162
MF Cetacean						158	129	10.2	153	153	168	139	10.2	163	163	175
HF Cetacean						159	129	10.3	154	153	169	139	10.3	164	163	175
PW						148	124	8.5	143	143	158	134	8.5	153	153	165
OW						145	123	7.7	141	140	155	133	7.7	151	150	162
Far-Field Hydrophone																
Unweighted	164	150	3.5	158	156	149	132	4.2	142	140	159	142	4.2	152	150	164
LF Cetacean						132	123	2.4	130	130	142	133	2.4	140	140	152
MF Cetacean						143	126	3.9	136	134	153	136	3.9	146	144	158
HF Cetacean						143	127	4.0	137	134	153	137	4.0	147	144	158
PW						134	122	2.7	130	129	144	132	2.7	140	139	151
OW						133	123	2.6	129	129	143	133	2.6	139	139	151

Note: Measurement distances normalized to 33 feet (10 meters)


Sound Pressure during Pile Driving
Sound Pressure, Pa
Time, Seconds
Peak Waveform, Pa
Sound Pressure, Pa
Time, Seconds
Spectrogram
Frequency, Hz
Time, Seconds
Frequency Spectra
SPL, dB re: 1 uPa
Frequency, Hz

REMOVAL – 4

February 6, 2024

Airborne Sound Levels, dB re: 20 μPa

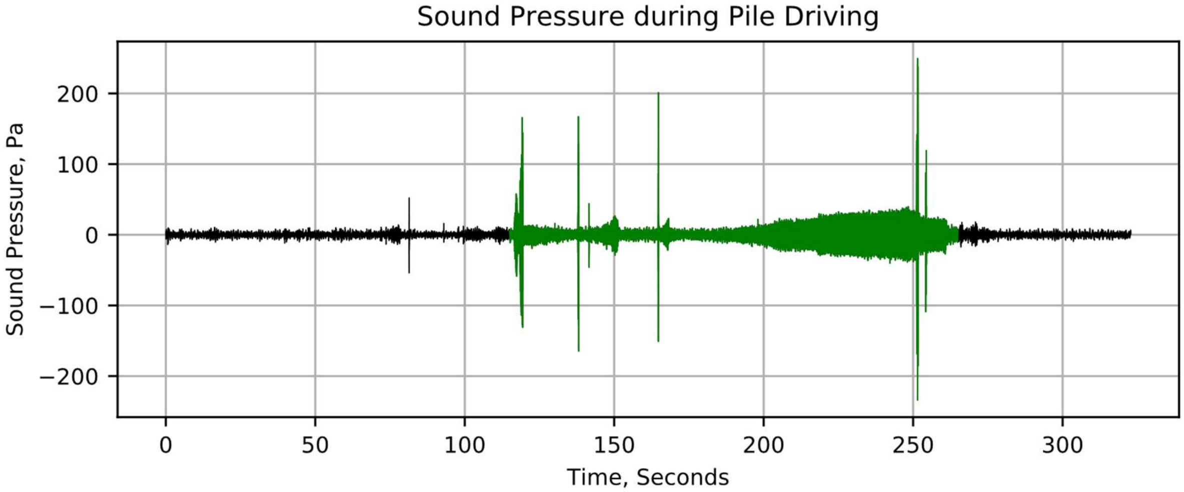
Median	Minimum	Maximum
87	83	91

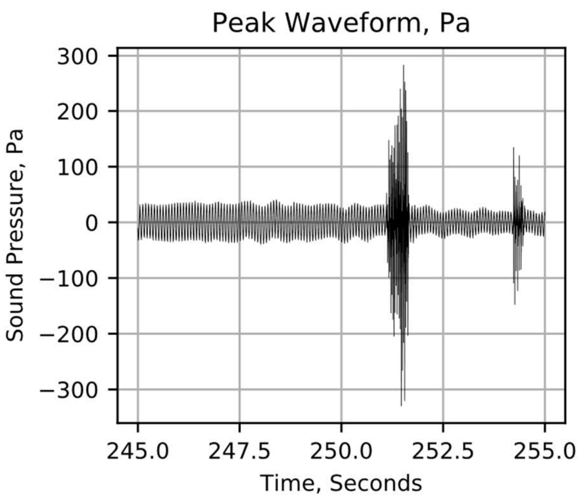
Airborne Frequency Spectrum

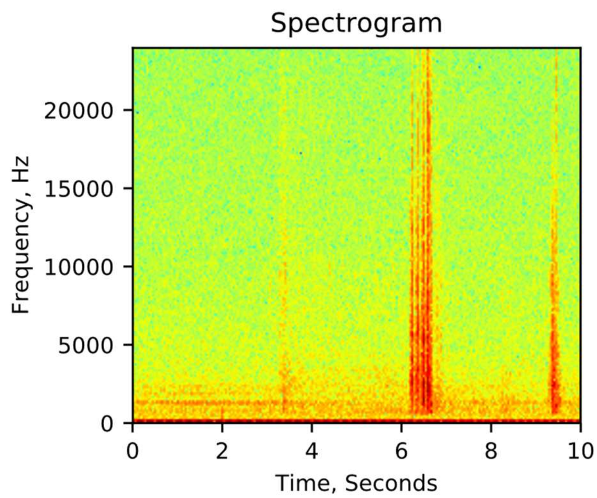
Underwater Sound Levels, dB re: 1 μPa

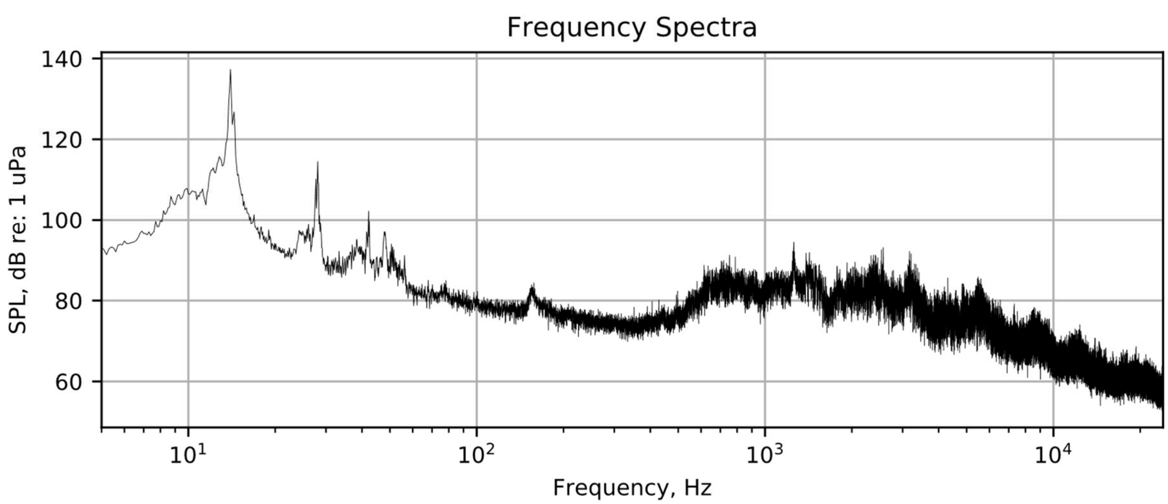
Frequency Range	Peak					RMS					SEL					cSEL
	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	
Near-Field Hydrophone																
Unweighted	173	153	5.3	166	163	157	140	5.6	152	148	167	150	5.6	162	158	173
LF Cetacean						137	124	4.1	133	131	147	134	4.1	143	141	155
MF Cetacean						150	134	5.5	145	142	160	144	5.5	155	152	167
HF Cetacean						151	134	5.5	146	142	161	144	5.5	156	152	168
PW						141	125	4.8	136	133	151	135	4.8	146	143	158
OW						138	123	4.5	134	132	148	133	4.5	144	142	156
Far-Field Hydrophone																
Unweighted	178	147	9.2	169	156	153	132	6.8	148	144	163	142	6.8	158	154	170
LF Cetacean						140	122	4.8	133	132	150	132	4.8	143	142	155
MF Cetacean						147	127	6.5	142	138	157	137	6.5	152	148	164
HF Cetacean						148	127	6.6	143	138	158	137	6.6	153	148	164
PW						141	122	5.4	135	132	151	132	5.4	145	142	157
OW						141	122	5.1	134	132	151	132	5.1	144	142	156

Note: Measurement distances normalized to 33 feet (10 meters)


Sound Pressure during Pile Driving
Sound Pressure, Pa
Time, Seconds


Peak Waveform, Pa
Sound Pressure, Pa
Time, Seconds


Spectrogram
Frequency, Hz
Time, Seconds


Frequency Spectra
SPL, dB re: 1 uPa
Frequency, Hz

2.0 VIBRATORY PILE DRIVING

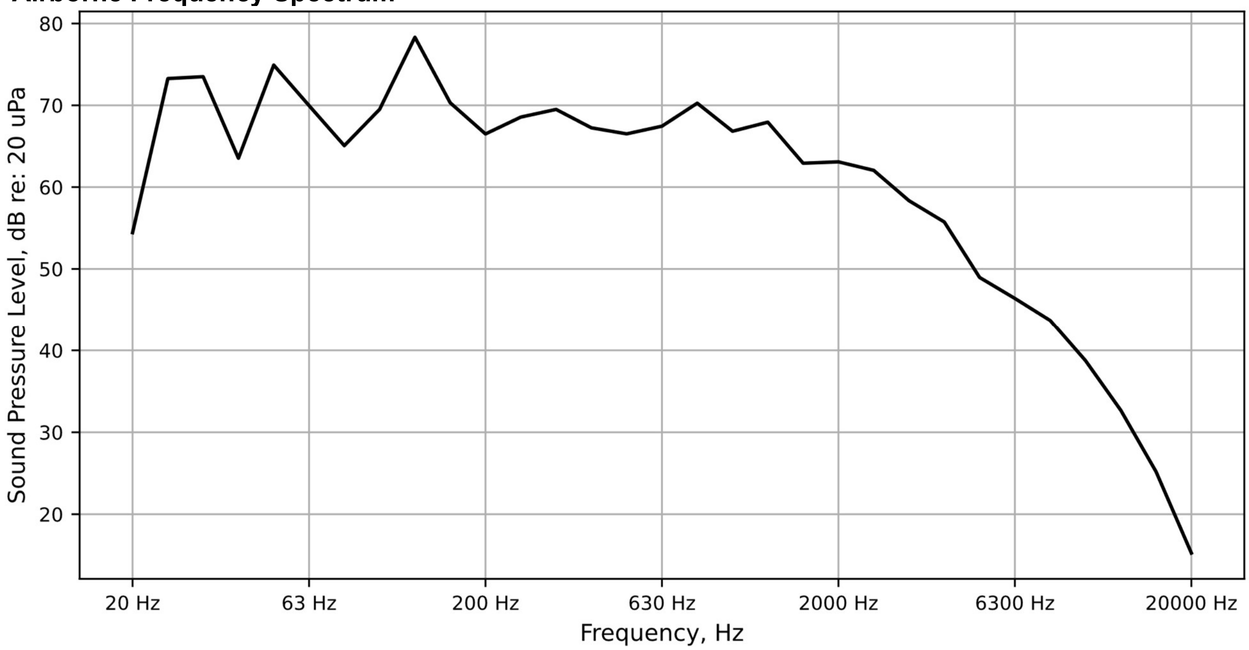
PILE – 1

February 6, 2024

Airborne Sound Levels, dB re: 20 μPa

Median	Minimum	Maximum
92	84	96

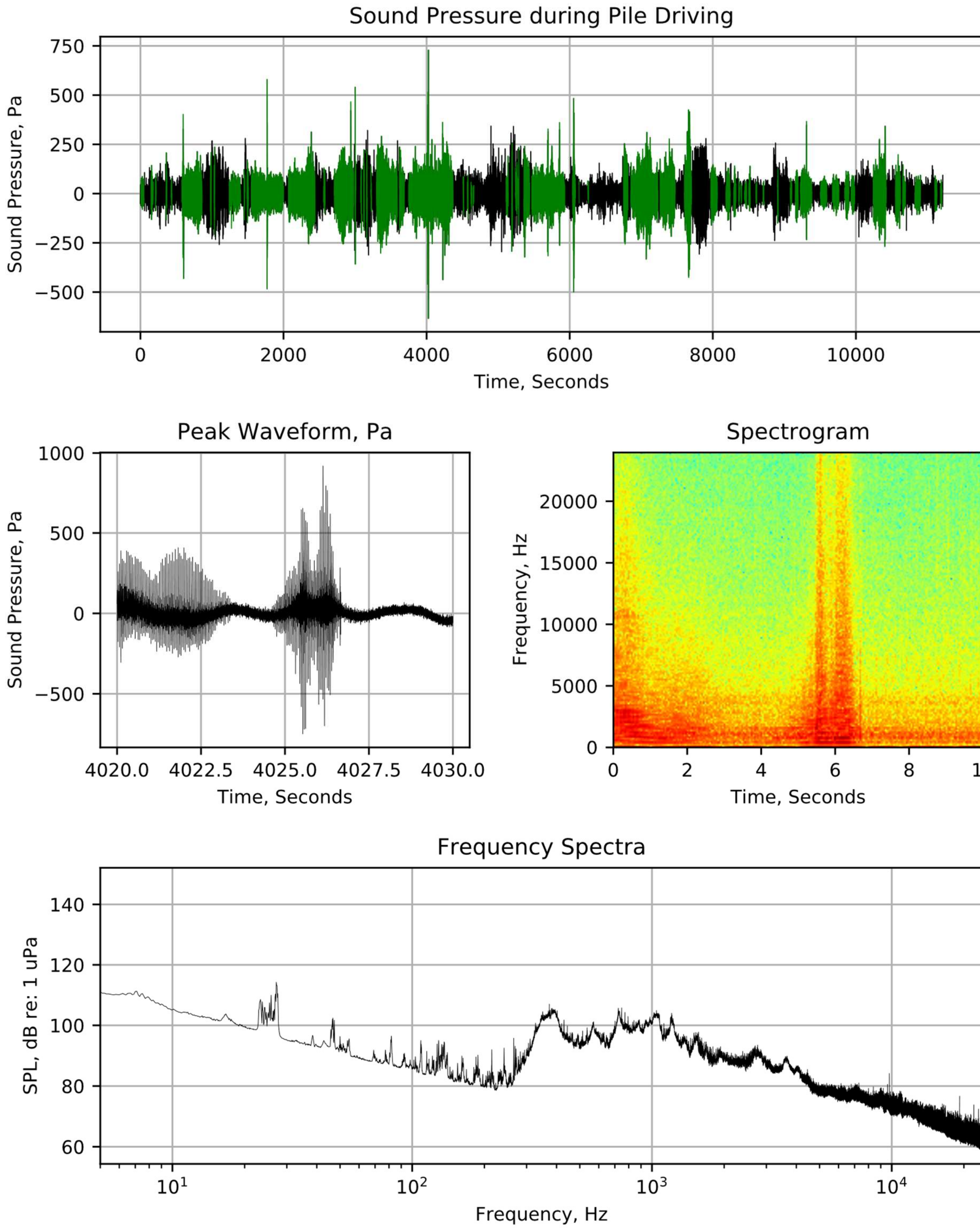
Airborne Frequency Spectrum



Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS					SEL					cSEL
	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	
Near-Field Hydrophone																
Unweighted	184	152	4.8	167	162	159	125	5.8	146	146	169	135	5.8	156	156	184
LF Cetacean						154	116	7.1	141	141	164	126	7.1	151	151	178
MF Cetacean						154	120	5.6	141	140	164	130	5.6	151	150	178
HF Cetacean						154	120	5.7	141	141	164	130	5.7	151	151	179
PW						152	116	6.3	139	138	162	126	6.3	149	148	176
OW						153	116	6.7	140	140	163	126	6.7	150	150	177
Far-Field Hydrophone																
Unweighted	185	144	5.3	165	159	156	126	6.1	144	144	166	136	6.1	154	154	182
LF Cetacean						151	120	6.5	139	138	161	130	6.5	149	148	176
MF Cetacean						152	122	5.6	139	138	162	132	5.6	149	148	176
HF Cetacean						152	122	5.7	139	138	162	132	5.7	149	148	176
PW						150	120	5.8	137	136	160	130	5.8	147	146	175
OW						151	120	6.2	139	138	161	130	6.2	149	148	176

Note: Measurement distances normalized to 33 feet (10 meters)


Sound Pressure during Pile Driving
Sound Pressure, Pa
Time, Seconds
Peak Waveform, Pa
Sound Pressure, Pa
Time, Seconds
Spectrogram
Frequency, Hz
Time, Seconds
Frequency Spectra
SPL, dB re: 1 uPa
Frequency, Hz

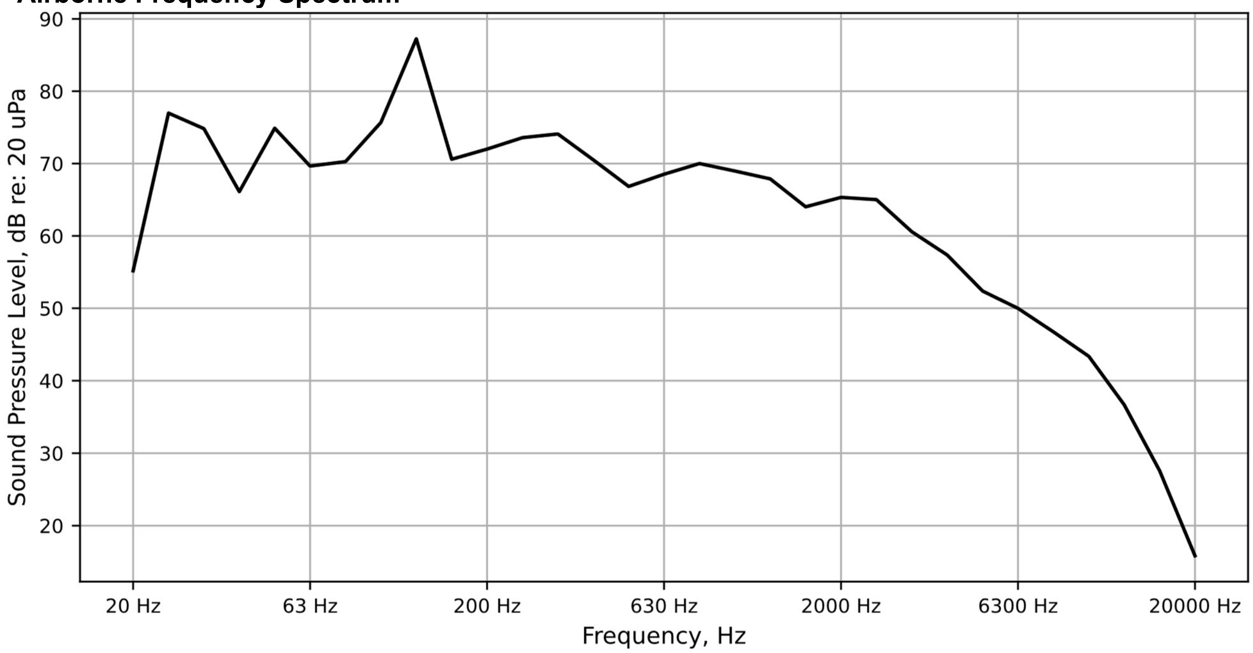
PILE – 2

February 7, 2024

Airborne Sound Levels, dB re: 20 μPa

Median	Minimum	Maximum
95	83	99

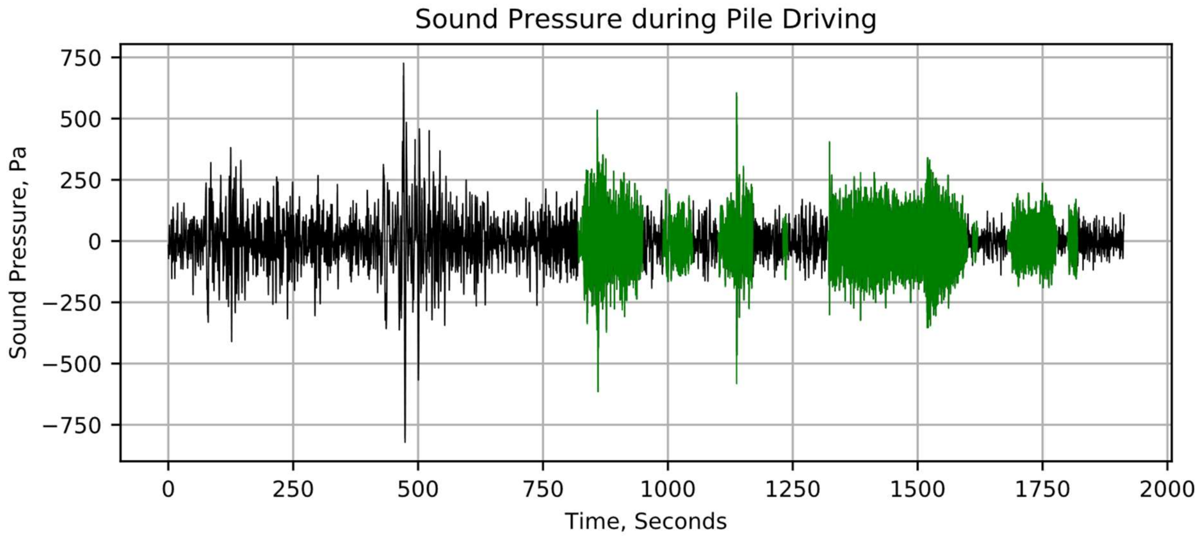
Airborne Frequency Spectrum

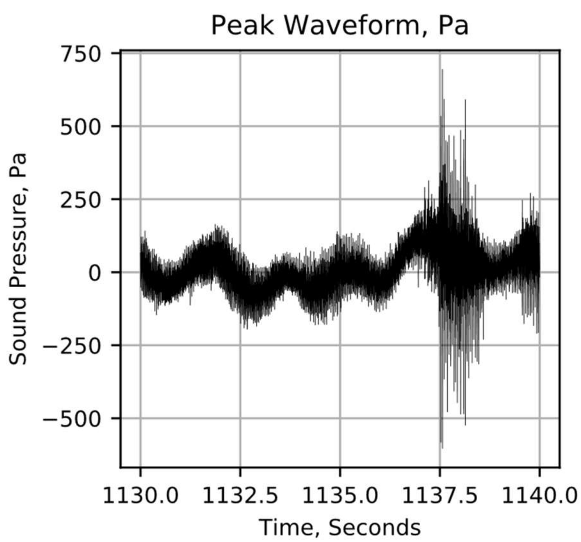


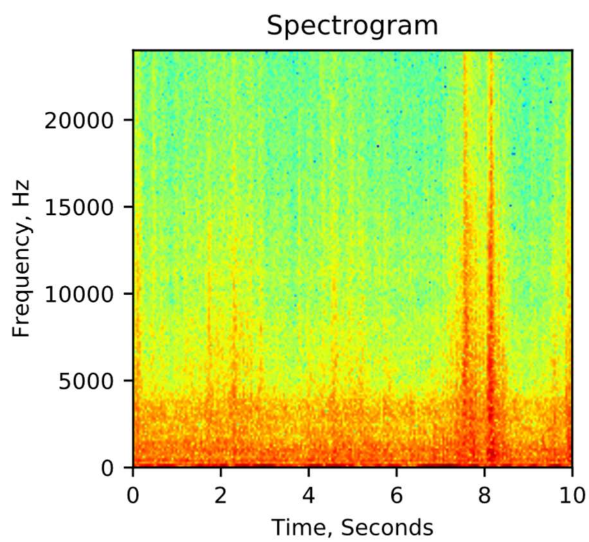
Underwater Sound Levels, dB re: 1 μPa

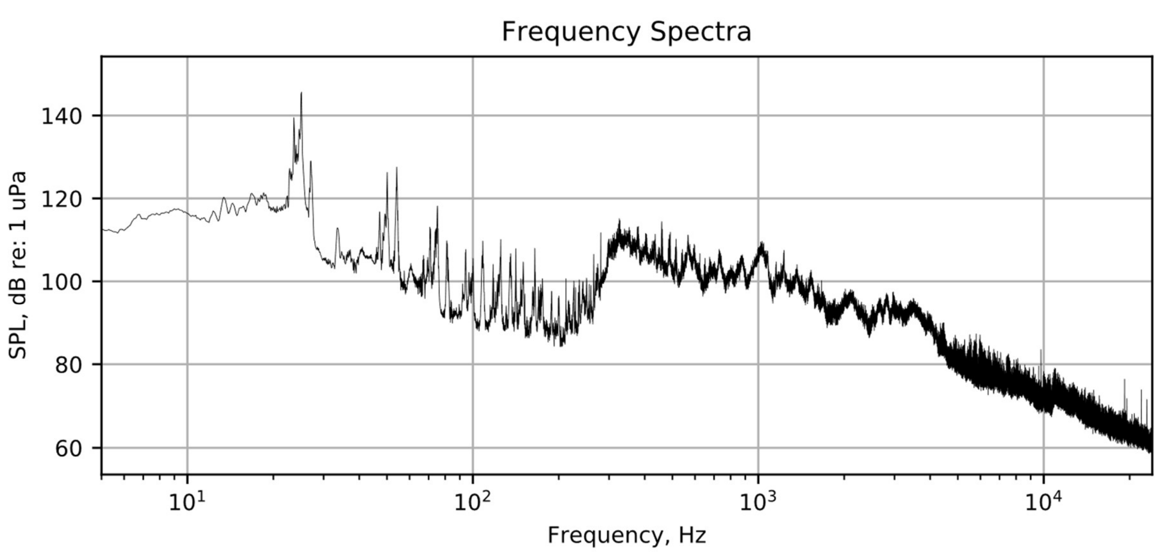
Frequency Range	Peak					RMS					SEL					cSEL
	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	
Near-Field Hydrophone																
Unweighted	176	157	3.9	166	163	158	132	5.3	152	151	168	142	5.3	162	161	181
LF Cetacean						148	123	4.4	141	141	158	133	4.4	151	151	170
MF Cetacean						151	127	5.1	146	145	161	137	5.1	156	155	174
HF Cetacean						152	127	5.1	147	146	162	137	5.1	157	156	175
PW						144	124	4.1	140	140	154	134	4.1	150	150	168
OW						144	124	4.0	139	140	154	134	4.0	149	150	168
Far-Field Hydrophone																
Unweighted	178	150	3.7	165	162	156	125	5.6	151	150	166	135	5.6	161	160	179
LF Cetacean						146	120	4.8	141	141	156	130	4.8	151	151	169
MF Cetacean						149	121	5.2	144	144	159	131	5.2	154	154	173
HF Cetacean						150	121	5.3	145	145	160	131	5.3	155	155	173
PW						145	120	4.4	139	139	155	130	4.4	149	149	168
OW						146	120	4.4	140	140	156	130	4.4	150	150	168

Note: Measurement distances normalized to 33 feet (10 meters)


Sound Pressure during Pile Driving
Sound Pressure, Pa
750
500
250
0
−250
−500
−750
0
250
500
750
1000
1250
1500
1750
2000
Time, Seconds


Peak Waveform, Pa
Sound Pressure, Pa
750
500
250
0
−250
−500
1130.0
1132.5
1135.0
1137.5
1140.0
Time, Seconds


Spectrogram
Frequency, Hz
20000
15000
10000
5000
0
0
2
4
6
8
10
Time, Seconds


Frequency Spectra
SPL, dB re: 1 uPa
140
120
100
80
60
10^1
10^2
10^3
10^4
Frequency, Hz

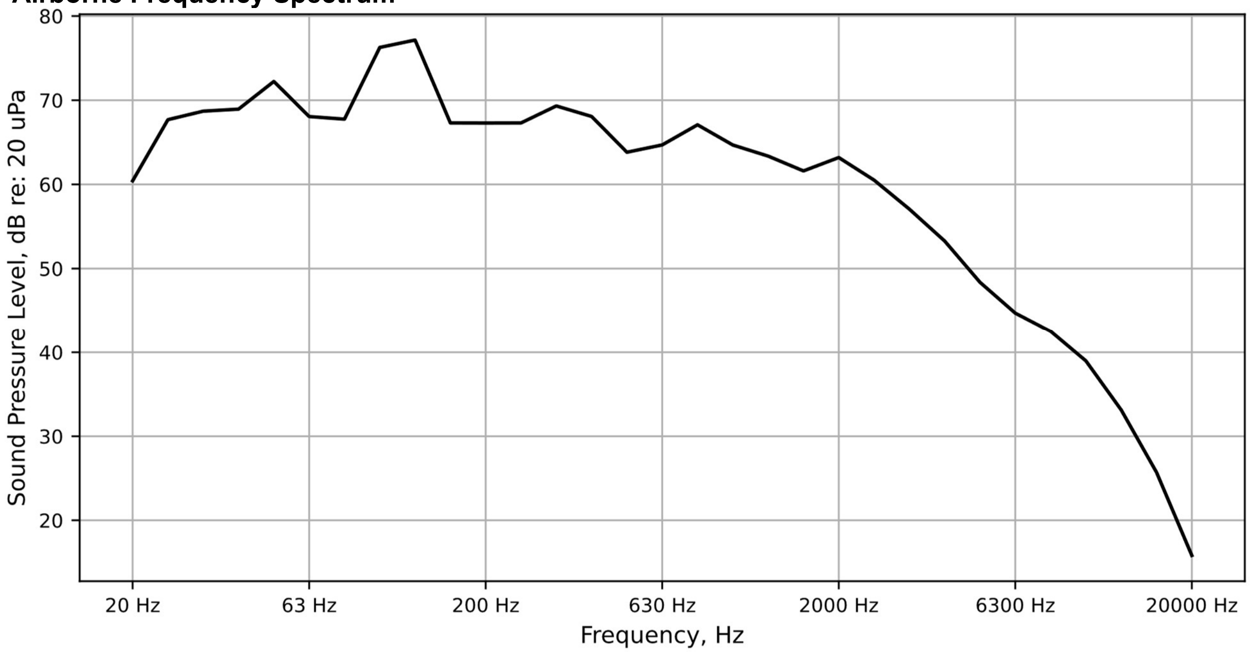
PILE – 3

February 7, 2024

Airborne Sound Levels, dB re: 20 μPa

Median	Minimum	Maximum
94	85	106

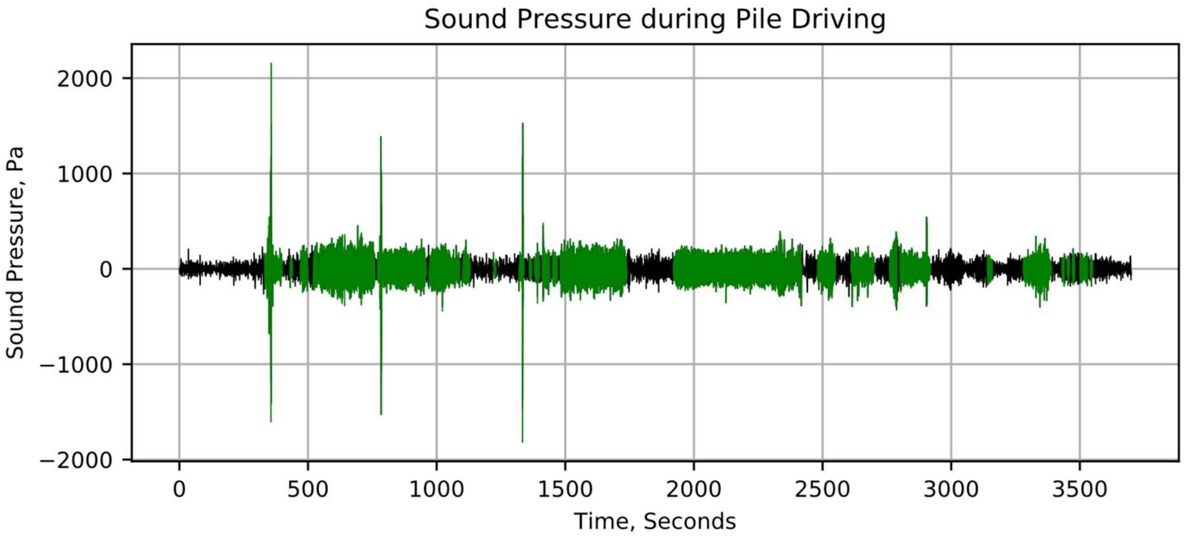
Airborne Frequency Spectrum

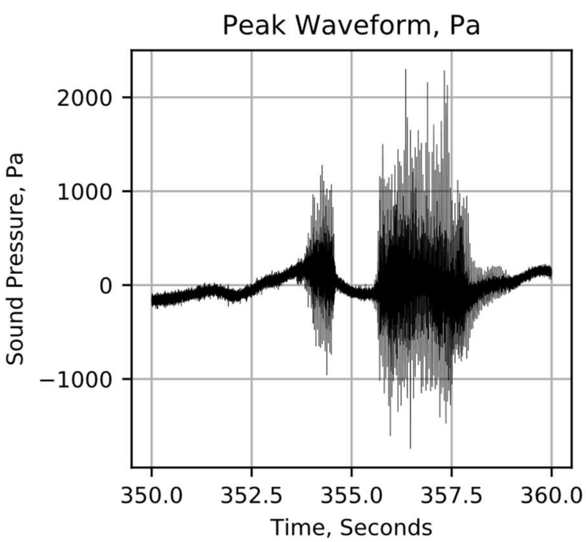


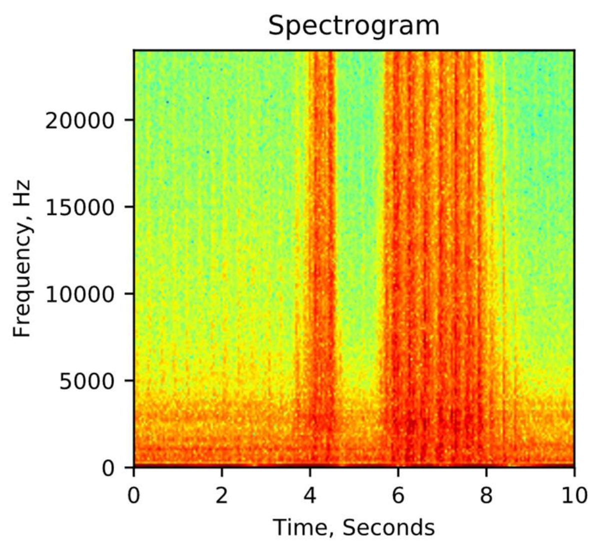
Underwater Sound Levels, dB re: 1 μPa

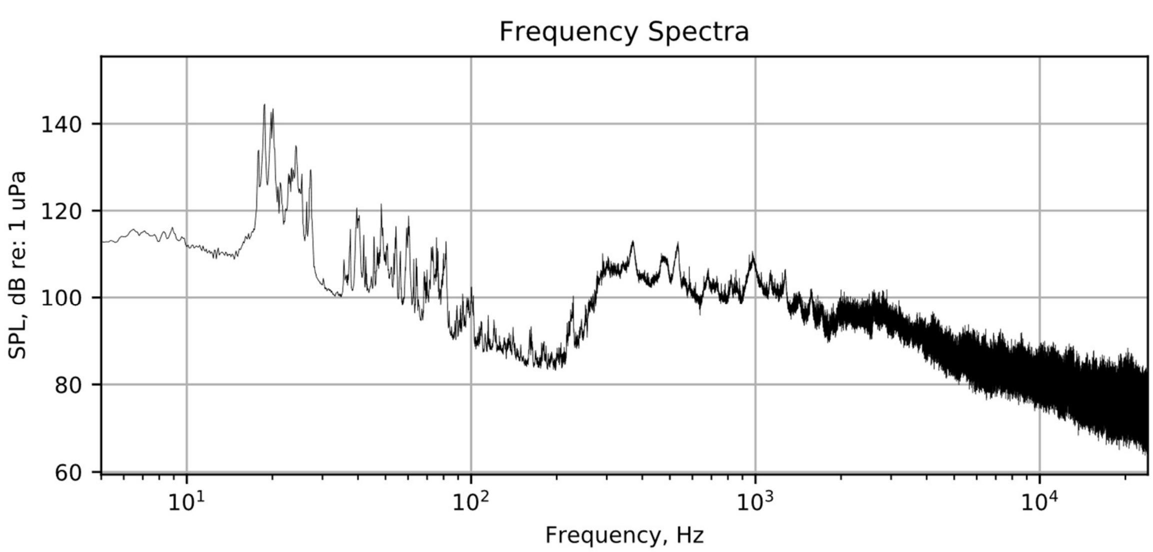
<table>
<tr><th rowspan="2">Frequency Range</th><th colspan="5">Peak</th><th colspan="5">RMS</th><th colspan="5">SEL</th><th rowspan="2">cSEL</th></tr>
<tr><th>Max</th><th>Min</th><th>SD</th><th>Mean</th><th>Med</th><th>Max</th><th>Min</th><th>SD</th><th>Mean</th><th>Med</th><th>Max</th><th>Min</th><th>SD</th><th>Mean</th><th>Med</th></tr>
<tr><td colspan="17">Near-Field Hydrophone</td></tr>
<tr><td>Unweighted</td><td rowspan="6">187</td><td rowspan="6">159</td><td rowspan="6">3.9</td><td rowspan="6">169</td><td rowspan="6">164</td><td>159</td><td>132</td><td>4.9</td><td>154</td><td>153</td><td>169</td><td>142</td><td>4.9</td><td>164</td><td>163</td><td>187</td></tr>
<tr><td>LF Cetacean</td><td>154</td><td>125</td><td>3.0</td><td>142</td><td>141</td><td>164</td><td>135</td><td>3.0</td><td>152</td><td>151</td><td>175</td></tr>
<tr><td>MF Cetacean</td><td>156</td><td>129</td><td>4.7</td><td>148</td><td>147</td><td>166</td><td>139</td><td>4.7</td><td>158</td><td>157</td><td>181</td></tr>
<tr><td>HF Cetacean</td><td>156</td><td>129</td><td>4.8</td><td>148</td><td>147</td><td>166</td><td>139</td><td>4.8</td><td>158</td><td>157</td><td>181</td></tr>
<tr><td>PW</td><td>154</td><td>125</td><td>3.3</td><td>141</td><td>140</td><td>164</td><td>135</td><td>3.3</td><td>151</td><td>150</td><td>174</td></tr>
<tr><td>OW</td><td>154</td><td>125</td><td>3.0</td><td>141</td><td>139</td><td>164</td><td>135</td><td>3.0</td><td>151</td><td>149</td><td>174</td></tr>
<tr><td colspan="17">Far-Field Hydrophone</td></tr>
<tr><td>Unweighted</td><td rowspan="6">185</td><td rowspan="6">150</td><td rowspan="6">4.6</td><td rowspan="6">168</td><td rowspan="6">162</td><td>159</td><td>127</td><td>4.6</td><td>150</td><td>149</td><td>169</td><td>137</td><td>4.6</td><td>160</td><td>159</td><td>184</td></tr>
<tr><td>LF Cetacean</td><td>153</td><td>121</td><td>4.0</td><td>142</td><td>141</td><td>163</td><td>131</td><td>4.0</td><td>152</td><td>151</td><td>175</td></tr>
<tr><td>MF Cetacean</td><td>156</td><td>123</td><td>4.3</td><td>145</td><td>143</td><td>166</td><td>133</td><td>4.3</td><td>155</td><td>153</td><td>178</td></tr>
<tr><td>HF Cetacean</td><td>156</td><td>123</td><td>4.4</td><td>145</td><td>144</td><td>166</td><td>133</td><td>4.4</td><td>155</td><td>154</td><td>178</td></tr>
<tr><td>PW</td><td>154</td><td>122</td><td>3.8</td><td>140</td><td>139</td><td>164</td><td>132</td><td>3.8</td><td>150</td><td>149</td><td>173</td></tr>
<tr><td>OW</td><td>154</td><td>122</td><td>3.8</td><td>141</td><td>139</td><td>164</td><td>132</td><td>3.8</td><td>151</td><td>149</td><td>174</td></tr>
</table>

Note: Measurement distances normalized to 33 feet (10 meters)


Sound Pressure during Pile Driving
Sound Pressure, Pa
2000
1000
0
−1000
−2000
0
500
1000
1500
2000
2500
3000
3500
Time, Seconds


Peak Waveform, Pa
Sound Pressure, Pa
2000
1000
0
−1000
350.0
352.5
355.0
357.5
360.0
Time, Seconds


Spectrogram
Frequency, Hz
20000
15000
10000
5000
0
0
2
4
6
8
10
Time, Seconds


Frequency Spectra
SPL, dB re: 1 uPa
140
120
100
80
60
10^1
10^2
10^3
10^4
Frequency, Hz

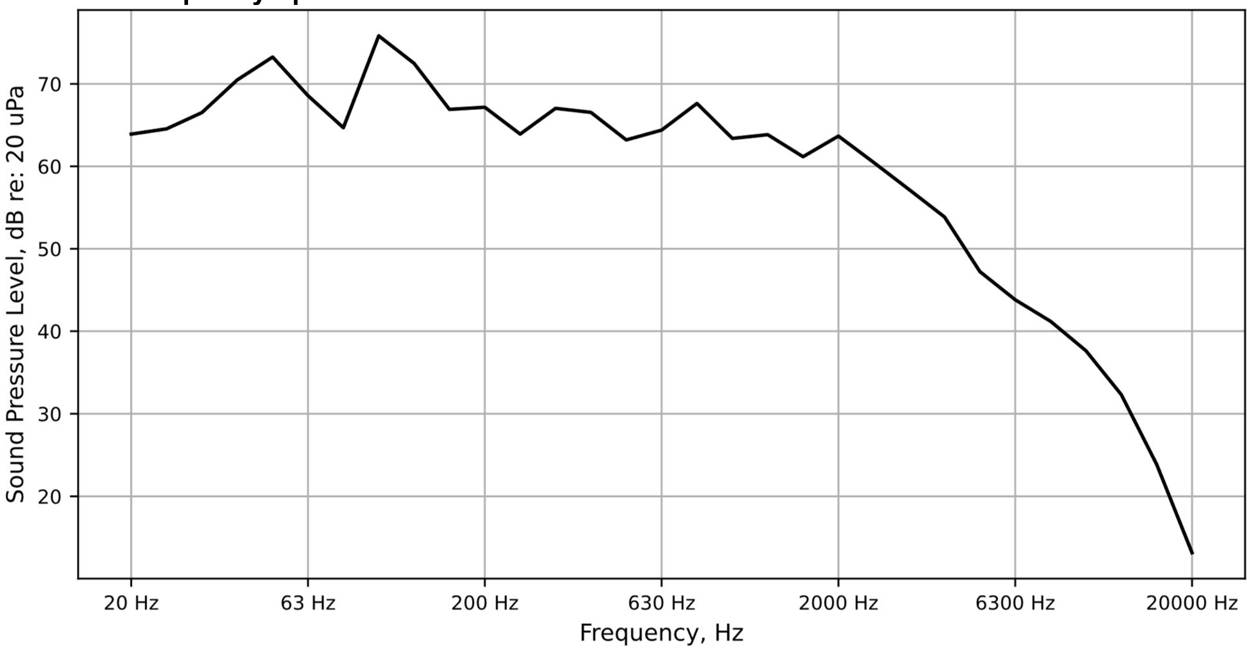
PILE – 4

February 7, 2024

Airborne Sound Levels, dB re: 20 μPa

Median	Minimum	Maximum
91	88	96

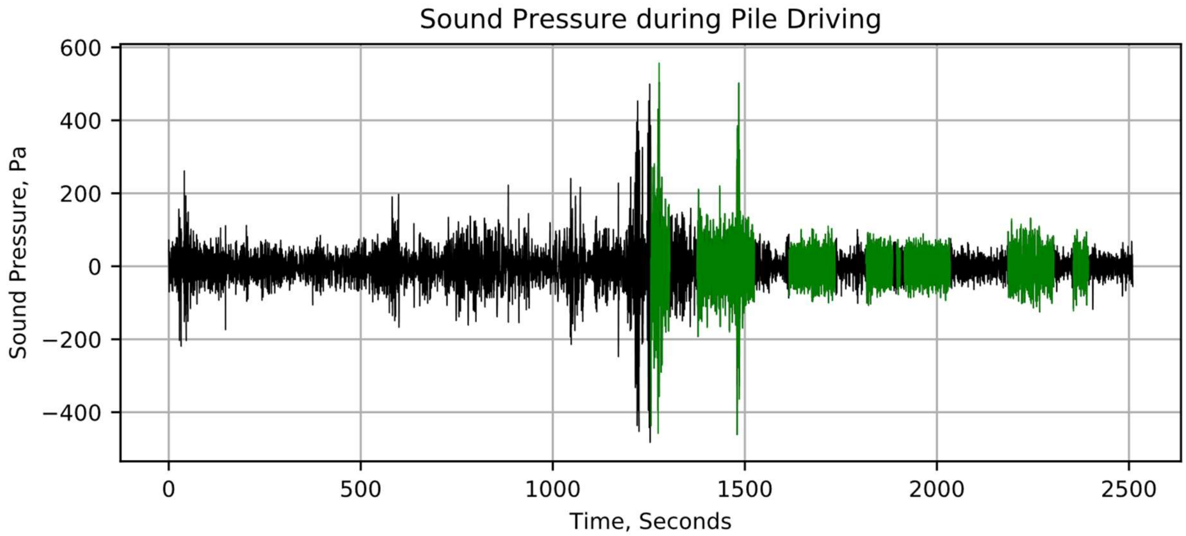
Airborne Frequency Spectrum

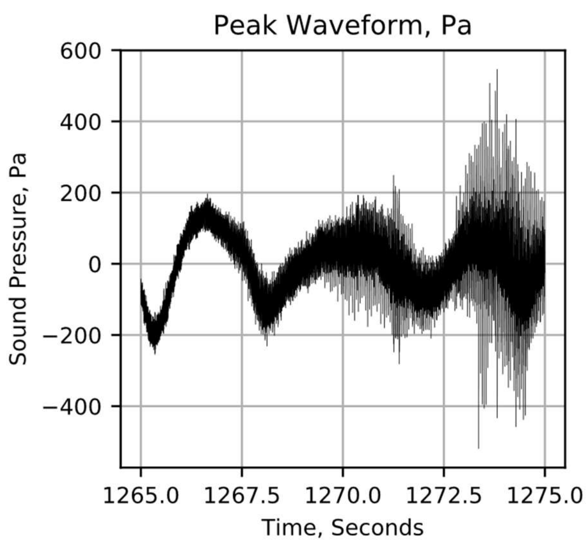


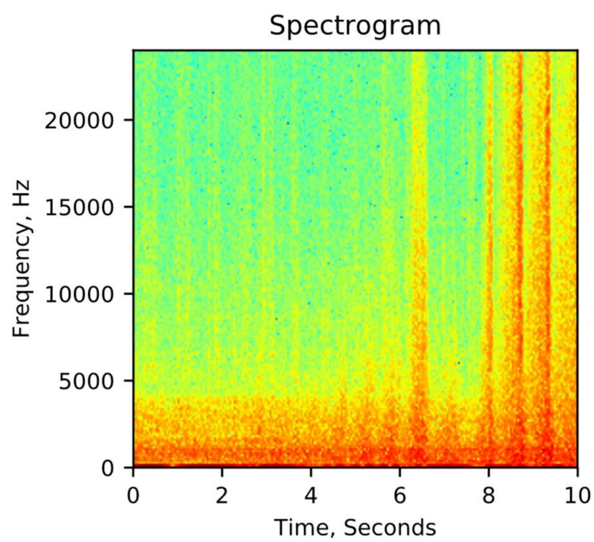
Underwater Sound Levels, dB re: 1 μPa

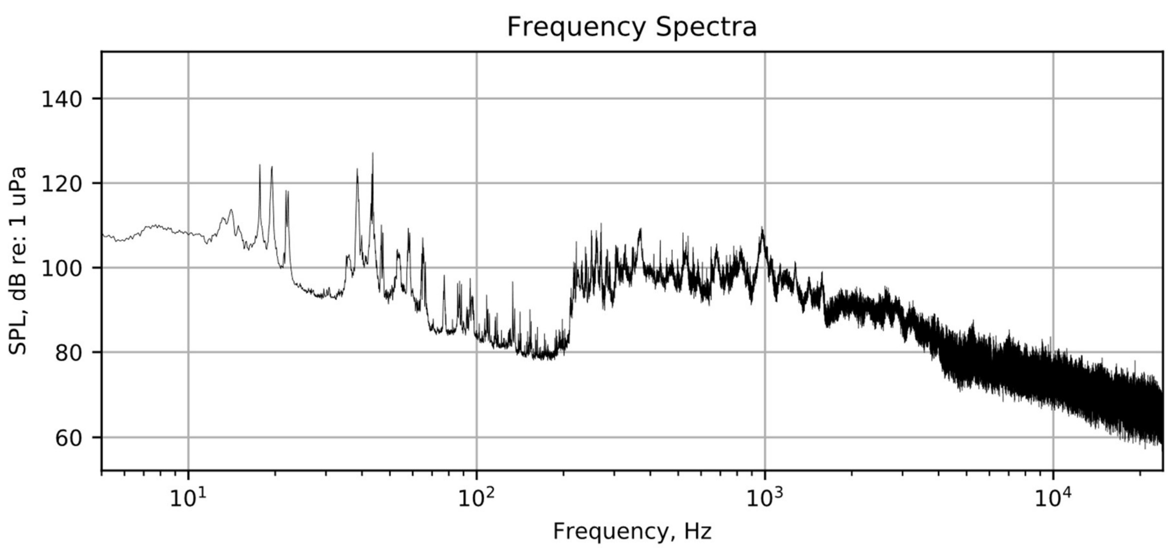
Frequency Range	Peak					RMS					SEL					cSEL
	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	
Near-Field Hydrophone																
Unweighted	179	157	4.8	167	159	156	143	2.6	147	144	166	153	2.6	157	154	175
LF Cetacean						150	137	2.4	140	139	160	147	2.4	150	149	169
MF Cetacean						150	137	2.7	141	138	160	147	2.7	151	148	169
HF Cetacean						151	138	2.6	141	139	161	148	2.6	151	149	170
PW						147	134	2.5	138	136	157	144	2.5	148	146	166
OW						148	135	2.4	139	137	158	145	2.4	149	147	167
Far-Field Hydrophone																
Unweighted	178	146	5.2	165	157	154	134	2.9	144	142	164	144	2.9	154	152	172
LF Cetacean						149	122	3.2	139	137	159	132	3.2	149	147	167
MF Cetacean						148	128	2.9	138	137	158	138	2.9	148	147	167
HF Cetacean						149	129	2.9	139	137	159	139	2.9	149	147	167
PW						146	122	3.1	136	134	156	132	3.1	146	144	165
OW						147	122	3.2	137	136	157	132	3.2	147	146	166

Note: Measurement distances normalized to 33 feet (10 meters)


Sound Pressure during Pile Driving
Sound Pressure, Pa
Time, Seconds


Peak Waveform, Pa
Sound Pressure, Pa
Time, Seconds


Spectrogram
Frequency, Hz
Time, Seconds


Frequency Spectra
SPL, dB re: 1 uPa
Frequency, Hz

PILE – 5

February 7, 2024

Airborne Sound Levels, dB re: 20 μPa

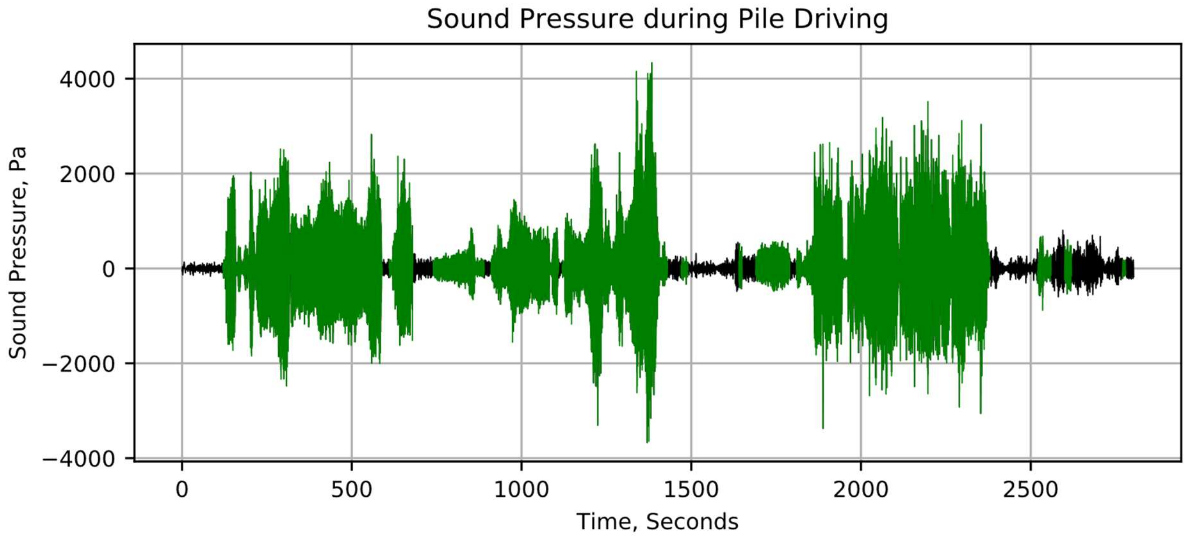
Median	Minimum	Maximum
96	91	100

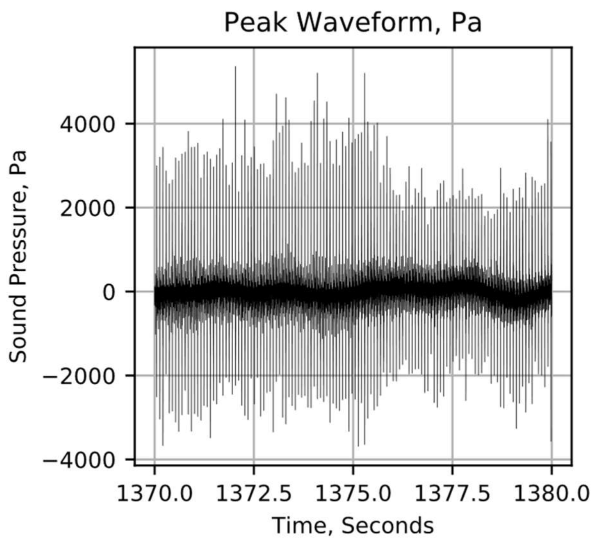
Airborne Frequency Spectrum

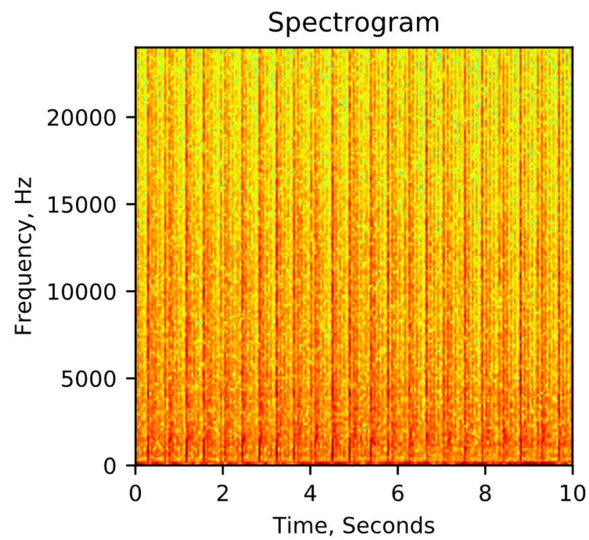
Underwater Sound Levels, dB re: 1 μPa

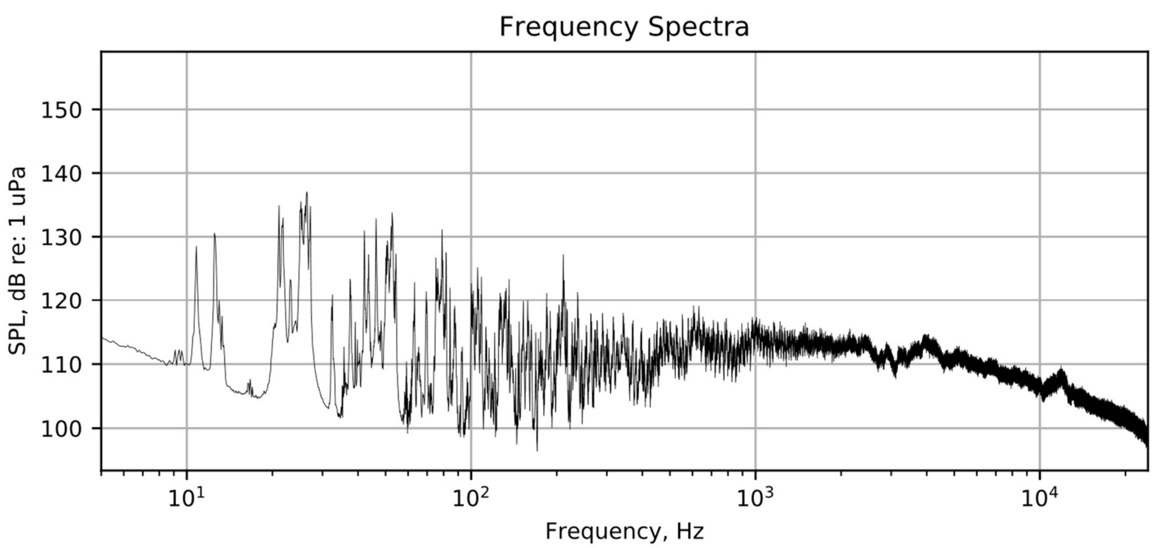
Frequency Range	Peak					RMS					SEL					cSEL
	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	Max	Min	SD	Mean	Med	
Near-Field Hydrophone																
Unweighted	193	164	7.2	184	182	166	132	5.5	160	160	176	142	5.5	170	170	193
LF Cetacean						161	123	6.2	155	154	171	133	6.2	165	164	187
MF Cetacean						164	127	6.7	158	157	174	137	6.7	168	167	191
HF Cetacean						163	128	6.4	157	156	173	138	6.4	167	166	190
PW						162	124	7.1	156	155	172	134	7.1	166	165	189
OW						161	123	6.9	156	155	171	133	6.9	166	165	189
Far-Field Hydrophone																
Unweighted	192	158	7.2	184	183	168	129	6.0	162	161	178	139	6.0	172	171	195
LF Cetacean						162	123	6.0	156	156	172	133	6.0	166	166	189
MF Cetacean						165	125	6.7	158	157	175	135	6.7	168	167	191
HF Cetacean						164	125	6.6	158	157	174	135	6.6	168	167	191
PW						163	123	6.8	157	156	173	133	6.8	167	166	190
OW						163	124	6.5	157	157	173	134	6.5	167	167	190

Note: Measurement distances normalized to 33 feet (10 meters)


Sound Pressure during Pile Driving
Sound Pressure, Pa
Time, Seconds


Peak Waveform, Pa
Sound Pressure, Pa
Time, Seconds


Spectrogram
Frequency, Hz
Time, Seconds

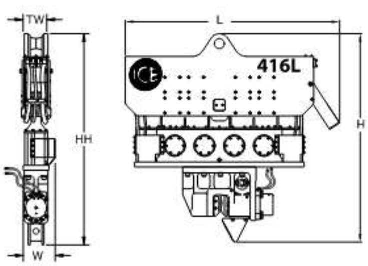

Frequency Spectra
SPL, dB re: 1 uPa
Frequency, Hz

3.0 ICE MODEL 416L HYDRAULIC VIBRATORY DRIVER/EXTRACTOR

ICE® Model 416L Hydraulic Vibratory Driver/ Extractor with Model 350G Power Unit

WWW.ICEUSA.COM
888-ICE-USA1

The most popular vibratory hammer for international clients since 1974.
Narrow throat width for U-shaped sheet piles.
Up to 40 tons (356 kN) line pull for extraction.



ICE Model 416L Vibratory Pile Hammer		
Eccentric moment	2200 in-lbs	25 kg-m
Maximum frequency	1700 vpm	
Driving Force	100 tons	886 kN
Centrifugal force	90 tons	790 kN
Amplitude (free w/o clamp)	0.9 in	23 mm
Standard line pull for extracting	40 tons	355 kN
Maximum line pull for extracting	40 tons	355 kN
Weight (no clamp or hoses)	7850 lbs	3560 kg
Non-vibrating Weight	3060 lbs	1390 kg
Height without clamp (H)	70 in	1780 mm
Length (L)	95 in	2415 mm
Width (W)	17 in	435 mm
Throat width (TW)	14 in	356 mm
Hydraulic hose length	150 ft	30 m
Hydraulic hose weight	1425 lbs	650 kg
Height with sheeting clamp (HH)	108 in	2740 mm
Weight with sheeting clamp & 1/2 hoses	10765 lbs	4880 kg
Height with beam & caisson clamps	96 in	2440 mm
Weight with beam, caisson clamps & 1/2 hoses	11500 lbs	5215 kg
ICE Model 350G Power Unit		
Engine	Caterpillar C9	
EPA/EU Emissions rating	Tier 3	Stage IIIA
Power	350 HP	261 kW
Operating speed	1950 rpm	1850 rpm
Maximum motors pressure	5500 psi	380 bar
Motors flow (no load)	100 gpm	385 lpm
Clamp pressure	4500 psi	310 bar
Clamp flow	6 gpm	20 lpm
Weight (w/ full fluid & 1/2 fuel)	11350 lbs	5150 kg
Length	130 in	3300 mm
Width	63 in	1600 mm
Height	87 in	2200 mm
Hydraulic oil capacity	275 gal	1040 liters
Fuel Capacity	118 gal	445 liters

INTERNATIONAL CONSTRUCTION EQUIPMENT 40 1974 · 2014 YEARS OF EXCELLENCE

DESIGNED AND MANUFACTURED IN USA BY ICE®
WORLD LEADER IN COST-EFFECTIVE FOUNDATION EQUIPMENT SINCE 1974.

Constant improvement and engineering progress make it necessary that ICE®, Inc reserve the right to make specification changes without notice. Please consult ICE® for the latest available information.

4.0 APE MODEL 200 VIBRATORY DRIVER EXTRACTOR

APE Model 200 Vibratory Driver Extractor

The Worlds Largest Provider of Foundation Construction Equipment

SPECIFICATIONS	DATA
Eccentric Moment	4,400 in-lbs (50.69 kgm)
Drive Force	170 tons (1,513 kN)
Frequency Maximum (VPM)	0 - 1,650 vpm
Max Line Pull	133 tons (1,183 kN)
Bare Hammer Weight w/o Clamp	12,760 lbs (5,788 kg)
Throat Width	14.75 in (37 cm)
Length	104.00 in (264 cm)
Height w/o Clamp	65.50 in (166 cm)

APE Model 595 Power Unit

SPECIFICATIONS	DATA
Engine Type	Caterpillar C15 Tier III
Horse Power	595 HP (438 kW)
Drive Pressure	0 - 4,500 psi (310 bar)
Drive Flow	188 gpm (712 lpm)
Clamp Pressure	4,800 psi (69,618 bar)
Clamp Flow	10 gpm (3 lpm)
Engine Speed	2,100 rpm
Weight	19,500 lbs (8,845 kg)
Length	152 in (385 cm)
Width	82 in (208 cm)
Height	94 in (239 cm)
Hydraulic Reservoir	575 gal (2,177 L)
Fuel Capacity	160 gal (606 L)

Specifications may vary due to site conditions, specific hammer conditions or product set up.
Specifications may change without notice.
Consult the factory for details on any specific product (800) 248-8498.

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